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Effects of traditional strength vs. complex training on maximal strength and functional capacity in U19 professional soccer players

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“A viagem nunca acaba, apenas os viajantes acabam. E mesmo estes podem prolongar-se em memória, em lembrança, em narrativa...”

“É preciso voltar aos passos que foram dados, para repetir e para traçar caminhos novos ao lado deles. É preciso recomeçar a viagem sempre”.

- José Saramago -

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Abstract

The purpose of this dissertation was to compare the effects of traditional strength (TST) vs complex strength training (CST) on maximal strength (1RM) and functional capacity in U19 soccer players. Twenty-six professional U19 male soccer players (estimated peak height velocity, PHV=2.6±1.0 yrs.) were divided in a TST group (weightlifting exercises; *n*=9), a CST group (weightlifting exercises combined with plyometrics; *n*=11) and a control group (CON; regular team' soccer training; *n*=6). 1RM was estimated and functional capacities were evaluated at the start and the end of a 4-week preparatory period. Both TST and CST group improved in 1RM bench press and back squat (1RM-BP, 1RM-BS; *d*=0.67–0.91; *P*<0.05). The CST group improved squat jump (SJ) and countermovement jump (CMJ), 10-, 20- and 30-m sprint and Yo-Yo intermittent recovery test – level 1 (Yo-Yo IR1) performance (*d*=0.43–0.74; *P*<0.05), whereas CON group improved CMJ (*d*= 0.73; *P*=0.014). After adjustment for PHV and training load (TL, session-rating of perceived exertion), it was not observed any significant change for the CST and CON group (*P*>0.05). Concerning TST group, changes in SJ and 10-m sprint has appeared when adjusted for PHV, as well as changes in Yo-Yo IR1 performance when adjusted for TL (*d*=44–0.73; *P*<0.05). Independently of PHV and TL, moment × group interactions remained significant (*P*<0.05). No between-groups differences were observed in s-RPE neither after gym training nor field training (*P*>0.05). In conclusion, adding CST and TST based on vertical and horizontal force-vector exercises twice per week to regular soccer training during the preparatory period induced gains in 1RM. Additionally, the CST was more effective to induce improvements in functional capacities than the TST, ranked with similar perceived exertion. The positive CST-induced functional effects are likely mediated by biological maturation and TL.

Keywords: Team sports, Jump, Sprint, Power, Biological maturation.

Resumo

O objetivo desta dissertação foi comparar os efeitos de um programa de treino tradicional de força (TTF) com um programa de treino complexo de força (TCF) na força máxima (1RM) e na aptidão física de jogadores de futebol sub19. Vinte e seis jogadores profissionais de futebol masculino do escalão sub19 (pico de velocidade de crescimento estimado: PVC= 2.6±1.0 anos) foram divididos em três grupos e sujeitos a diferentes programas de treino: grupo TTF (levantamento de pesos; *n*=9), grupo TCF (levantamento de pesos combinado com exercícios pliométricos; *n*=11) e grupo controlo (CON; treino regular de futebol; *n*=6). A 1RM foi estimada e as capacidades funcionais avaliadas antes e depois dos programas de treino, realizados no período preparatório. Os grupos TTF e TCF presentaram melhorias na 1RM de supino e agachamento (1RM-BP, 1RM-BS; *d*=0.67–0.91; *P*<0.05). O grupo TCF obteve ganhos de desempenho no *squat jump* (SJ) e no salto com contra movimento (CMJ), na velocidade aos 10, 20 e 30-m, assim como no *Yo-Yo Intermittent recovery test – level 1* (Yo-Yo IR1; *d*=0.43–0.74; *P*<0.05). Depois de ajustar a análise à PVC e à carga de treino (CT; duração da sessão × percepção subjetiva do esforço), os aumentos de performance obtidos pelos grupos CST e CON desapareceram (*P*>0.05). No entanto, no grupo TTF verificam-se aumentos de desempenho no SJ e na velocidade aos 10-m, quando a análise foi ajustada ao PVC, bem como no teste Yo-Yo IR1, após ajustamento à CT (*d*=44–0.73; *P*<0.05). Independentemente do PVC e da CT, as interações momento × grupo, permaneceram significativas (*P*<0.05). Não foram observadas diferenças na CT entre grupos, quer no treino do ginásio, quer no treino regular de futebol (*P*<0.05). Em conclusão, durante o período preparatório, a realização de programas de treino da força do tipo TCF e TTF, duas vezes por semana, conjuntamente com o treino regular de futebol, induziu aumentos significativos na 1RM. No entanto, quando comparado com o TTF, o TCF revelou-se mais efetivo para a melhora das capacidades funcionais, sem ser percebido como mais exigente. Os efeitos funcionais positivos induzidos pelo TCF foram mediados pela maturação biológica e pela CT.

Palavras Chave: Jogos desportivos, impulsão vertical, sprint, potência, maturação.

Resumen

El objetivo de esta tesis fue comparar los efectos del entrenamiento tradicional de fuerza (ETF) con el entrenamiento complejo de fuerza (ECF), en la fuerza máxima (1RM) y aptitud física en jugadores de fútbol Sub-19. Veintiséis jugadores profesionales de futbol masculino U19 (estimación del pico máximo de crecimiento, PMC= 2.6 ± 1.0 años) fueron divididos en grupo ETF (levantamiento de pesas; *n*=9), grupo ECF (levantamiento de pesas combinado con pliometría; *n*=11) y un grupo control (CON; entrenamiento regular de fútbol; *n*=6). La estimación de 1RM y evaluación de las capacidades funcionales fueron realizadas al inicio y el final del periodo preparatorio de 4 semanas. Ambos, ETF e ECF mostraron mejoras en 1RM press de banca y sentadilla (1RM-BP, 1RM-BS; *d*=0.67–0.91; *P*<0.05). Sin embargo, el grupo CST mostró mejoras en *squat jump* (SJ), salto con contramovimiento (CMJ), velocidad en los 10, 20 y 30-m, así como en el desempeño del *Yo-Yo Intermittent recovery – level 1* (Yo-Yo IR1; *d*=0.43–0.74; *P*<0.05). Después de ser hechos los ajustes por PMC y carga de entrenamiento (CE; duración de la sesión × percepción subjetiva del esfuerzo), las mejoras obtenidas en los grupos ECF y CON desaparecieron (*P*>0.05), mientras que las mejoras en SJ y velocidad 10-m aparecieron en el grupo EFT cuando los ajustes se realizaron con PMC así como en el desempeño del Yo-Yo IR1 cuando los ajustes fueron hechos por CE (*d*=44–0.73*; P*<0.05). Independientemente de PMC y CE, las interacciones de momento × grupo permanecieron significativas (*P*>0.05). Además, no se observaron diferencias entre grupos en CE tanto después del entrenamiento en el gimnasio como en el entrenamiento regular *P*<0.05). En conclusión, adicionar al entrenamiento regular de fútbol ejercicios de fuerza con métodos como ECF y ETF en vectores horizontal y vertical, dos veces por semana, durante el periodo preparatorio parece inducir mejoras en 1RM. Adicionalmente, el método ECF fue más efectivo en mejoras de capacidades funcionales que el ETF sin que haya sido percibido como más exigente. No obstante, los efectos funcionales positivos inducidos por ECF probablemente estén mediados por la maduración biológica y la CE.

Palabras Clave: Deportes de equipo, salto vertical, velocidad, potencia, maduración biológica.

List of abbreviations

1RM	One repetition maximum
1RM-BS	One repetition maximum back squat
1RM-BP	One repetition maximum bench press
BS	Back squat
BP	Bench press
CMJ	Countermovement jump
COD	Change of direction
CST	Complex strength training
IAT	Illinois agility test
PHV	Peak height velocity
RPE	Rating of perceived exertion
SD	Standard deviation
SJ	Squat jump
SSC	Stretch-shortening cycle
TL	Training load
TST	Traditional strength training
T10	10-m sprint time
T20	20-m sprint time
T30	30-m sprint time
VO_{2max}	Maximal oxygen consumption
Yo-Yo IR1	Yo-Yo intermittent recovery test – level 1

Chapter 1 – Introduction

Irrespective of age and sex, soccer training and match-play are characterized by high-intensity intermittent demands including frequent changes in movement, velocity, and direction with several body impacts collisions or contacts between players (Zouita et al., 2016). To cope with these demands, young soccer players need a combination of strength, power, and prolonged exercise capacity.

Strength has been defined as the ability to exert force on external objects or exert large forces against gravity in order to manipulate their own body. Anyways, the importance of strength training in soccer is evident with a crescent number of original articles per year published in last years. Therefore, strength training in soccer is viewed as an essential training component in different populations and research fields (Ahtiainen et al., 2004; Andersen et al., 1994; Faigenbaum & McFarland, 2016; Hoff & Helgerud, 2004; Peña et al., 2016; Suchomel et al., 2016). As research progresses, different methods have been designed to improve muscular strength and functional capacity in soccer players.

Beyond regular soccer training itself, complementary strength training is reported as beneficial for general health and performance of soccer players (Silva et al., 2015; Stølen et al., 2005). For example, various studies have shown that additional resistance-based strength training promoted meaningful training improvements in maximal strength, power, functional capacities and, oxygen transport and delivery (Petersen et al., 2011; Zouita et al., 2016), increases bone mineral density (Seabra et al., 2012), and also as a component for reducing muscle injury risk (Zouita et al., 2016).

In this scenario, different methods have been designed to improve previous aforementioned aspects in professional young soccer players, including traditional (standard weightlifting) or mixed methods (combining resistance exercise to explosive movements; (Freitas et al., 2017; Raya & Sánchez, 2018; Silva et al., 2015)).

Physical training is normally prescribed not only according to individual needs, but also according to the seasonal stage. In this scenario, the preparatory period is particularly important to build or restore physical capacities in soccer players, placing a special emphasis on strength training (Silva et al., 2016), contrarily to the competitive periods where players undergo periods of congested fixtures emphasizing recovery and preparedness for the next match. Thus, the preparatory period represents a vital moment to establish generic strength and functional adaptations to be maintained throughout the season (Vassilis et al., 2019). Indeed, teams who perform a greater number of pre-season training sessions, have reduced the number of muscle injuries during the competitive period (Ekstrand et al., 2020).

Notwithstanding, resistance-based strength training has been frequently questioned in relation to the specific demands of the sports (e.g. movements velocity and execution). Therefore, increased attention has been paid to mixed methods based on a combination of resistance training to induce a potentiated neuromuscular state and sport-specific movements. The present dissertation is based on an original investigation aimed to compare two different strength training methods; the CST and TST added to the regular soccer training in young professional soccer players.

Chapter 2 – Literature review

This chapter describes the current state of knowledge about the physical demands in youth soccer and the profile of young soccer players to provide an insight into the sports demands and the athletic profiles studied. Additionally, strength training in young soccer players is revised, including program designs, physiological and performance adaptations as well as possible confounding factors. The use of mixed methods based on resistance exercise and sport-specific demands is emphasized.

2.1. Physical demands of youth soccer

Extensive match-analysis research is available in youth soccer, depending on age, competitive level and, field position. Young soccer players cover a total distance ranging from 7,000 to 10,000 m during official matches (Palucci Vieira et al., 2019). Although intense activity represents the 3.0 – 5.6% of the total distance, and 3.9 – 4.5% of the total time during a match, players perform 52 to 100 accelerations and change activity 1379 to 1459 times, every 4 s (Palucci Vieira et al., 2019). Furthermore, the laterally run (shuffle) on soccer players, that represents between 217 to 549 m throughout a game, it was also described (da Silva et al., 2007). In this context, Stølen et al. (2005), reported that 96% of sprint bouts during a soccer game are shorter than 30-m, with 49% being shorter than 10-m (Stølen et al., 2005). Moreover, the most crucial moments of the game such as winning ball possession, scoring, or conceding goals are dependent on the ability of the athlete to perform better the high-speed movements (Ferrete et al., 2014).

Among young players, age-related differences in match or training session must be considered since match running performance has reported that younger players cover great high-intensity running distance than older players (U15>U17), whereas physiological responses such as heart rate, are similar across age groups (>80% of their maximum heart rate (Mendez-Villanueva et al., 2013)). Regarding training sessions, Coutinho et al. (2015) showed that the total distance in the middle of a normal training week, were greater from U17 team than U15 and U19 measured by global positioning systems (Coutinho et al., 2015). However, Buchheit et al. (2010a) reported that in general older players perform a greater total distance and younger players can maintain high-intensity running better than older ones (Buchheit et al., 2010a).

Nevertheless, important aspects of young physical performance such as the ability to repeat sprints has been previously described. Thus, comparing U13 to U18 highly trained soccer players through time-motion analyses and individualized speed thresholds, Buchheit et al. (2010b) have reported that younger players realized a greater number of repeat sprints than the older (Buchheit et al., 2010b). A study done by Kelly et al. (2019) which compared elite, sub-elite youth, and elite senior Australian soccer players, revealed a higher total game time, and an overall progressive increase in high speed running, high accelerations, high deceleration and energy cost, across the competition tiers (e. g., sub-elite >elite youth; (Kelly et al., 2019)). On the other hand, Vigh-Larsen et al. (2018) reported that U19 players perform a higher number of accelerations, decelerations and total distance compared to senior players, and additionally, youth players perform as much high-intensity activities as senior players (Vigh-Larsen et al., 2018).

Moreover, the field position has a large influence on physical demands, thus, Mendez-Villanueva et al. (2013) described that the greatest distance, at low relative speeds, is covered by midfielders while the wide-midfielders and strikers cover more distance at high-intensity (Mendez-Villanueva et al., 2013). Those characteristics seem to reflect the positional requirements in which it must be considered that the playstyle might influence it (e.g., accelerating to create pre-planned spaces based in a game model. So far, it has been described an existing influence on total expenditure energy, bioenergetic requirements and, physical and psychological components, depending on the positional role on each player (Di Salvo & Pigozzi, 1998).

Irrespective of the aforementioned factors, young soccer players experience fatigue toward the end of the match showing a progressive decline in high-speed running, and temporarily (immediately after the most intense periods) during a match. Whereas physiological determinants leading to fatigue are mainly linked to the depletion of muscle glycogen during a soccer match (Mohr et al., 2005), neuromuscular function and intermittent exercise capacity also cover a meaningful role for match performance (Rebelo et al., 2014). Therefore, it would be important to establish training strategies to improve/maintain functional capacities since as previously described, there are specific requirements to reach better performance in professional young soccer players.

2.2. Profiling young soccer players

2.2.1. Anthropometric characteristics

It is well known that young soccer players could differ in basic anthropometric characteristics such as height, body mass and body fat. However, chronological age plays a key role in profiling young soccer players with individuals born in the first quarter of the year being usually taller, and heavier, than those born during the fourth quarter (Bernal-Orozco et al., 2020; Buchheit et al., 2014). Also, it was described that goalkeepers tend to be taller, while a higher average percentage of muscle mass was found among forwards (Bernal-Orozco et al., 2020; Gil et al., 2007; Rebelo et al., 2013) whereas defenders were characterized by a lower quantity of fat levels (Gil et al., 2007). Furthermore, it has been reported that changes in somatotype are influenced also according to the level of performance, which can be explained by increasing demands of trainings and competitions (Galaviz et al., 2018).

While acknowledging differences in basic anthropometric characteristics, it becomes fundamental to consider biological maturation (peak height velocity; PHV), players of the same chronological age-group, could differ in terms of physical growth and related components that interact with the sport's demands (Malina et al., 2015). The age of peak linear growth (deemed as age at PHV) is an indicator of somatic maturity representing the time of maximum growth in stature during adolescence (Malina et al., 2004). Growth refers to the increase in size from the birth to adulthood (Mendez-Villanueva et al., 2011), whereas maturation refers to the tempo and timing of progress towards the mature biological state (e.g. neural adaptations or muscle fiber type among others; (Malina et al., 2004)). With this in mind, assessing biological maturation (e.g. age from PHV) has specific application in testing soccer players of the same chronological age, since aspects such as training adaptations or talent development can be mediated by physical growth (Malina et al., 2015).

2.2.2. Maximal strength

The expression of maximal strength is important for generic performance in soccer players, given its large connection with relevant functional capacities (*r*= 0.71–0.94; (Wisloff et al., 2004)). At the same time, strength has become crucial in the players' long-term development since its evaluation can be used either as a physical performance indicator or as talent identification and selection processes at early ages (Pena-Gonzalez et al., 2019). Moreover, in addition to strength training adaptations, it must be considered that age and gender associated to changes in muscle size and strength during puberty have been attributed largely to aspects such as neuronal adaptations, muscle structure, increase and improvements in muscular coordination that include factors like; selective activation of motors units, synchronization, and increased recruitment of motor units (Chelly et al., 2009).

On the other hand, attention must be paid in relation with hormonal influences like changes in testosterone secretion, since authors such as Van Praagh and Doré (2002), have reported that hormonal changes could occur with behaviors of moderate increases during the early stages of puberty and then, quick increases between mid and late puberty stages in males influencing the strength adaptations (Van Praagh & Doré, 2002). However, theoretical better muscle adaptation through resistance-based training programs, could be partially explained by enhancements on hormonal profile and greater muscle mass associated with adolescence in post-PHV (Faigenbaum et al., 2013).

2.2.3. Functional capacity

Players need to transform their maximal strength into functional capacities such as jumping, changing direction, sprinting, and performing prolonged intermittent exercise. Vertical jump capacity is an important component of locomotive skills that are part of the athletic motor skill spectrum (Meylan et al., 2014; Ramirez-Campillo et al., 2015b) and also as discriminant markers between competitive standard in young soccer players (Rebelo et al., 2013). Performance in CMJ seems to increase with age (e. g., U17 > U15) and appears to be attributed to better performances related to maturity stages (Asadi et al., 2018; Pedretti et al., 2019).

However, some studies have reported differences related to field-positions in youth soccer, thus, Chena et al. (2015) have described that goalkeepers and forwards performed better either power (watts) and height (cm) in the SJ and CMJ in comparison to defenders and midfielders (Chena et al., 2015). At the same time, better performance in CMJ and SJ in center defenders and goalkeepers were reported by Lago-Penas et al. (2011).

Agility has been deemed as a fundamental capacity for soccer players, with a competitive match requiring to change direction every 2–4 seconds during a game, completing 700 changes of direction (Bangsbo et al., 2006). So far, agility performance seems to increase in concordance to the age in young soccer players since significant differences were observed by Rago et al. (2020), who compared senior, U18 and, U16 European soccer players at regional and national levels. Age-related differences showed that adults and U18 players were moderate to very large better performing COD than U16, whereas no significant differences were observed between adults and U18 players (Rago et al., 2020). However, Rebelo et al. (2013) highlighted some differences about agility in elite and non-elite U19 soccer players since elite players presented better agility performances than non-elite within all positional roles, thus, the authors attributed those differences to the differential experience and training time between elite and non-elite players.

Sprinting capacity is determinant with regard to decisive moments such a scoring a goal or making a defensive save (Djaoui et al., 2017). In young soccer players, performance in sprinting has been reported as related to the level of competition and the position-specific demands of match play (Rebelo et al., 2013). A certain agreement exists in the fact that forwards perform better sprint tests, this provoked, among others, by their constant use during training sessions and matches (Gil et al., 2007). About age-related, enhancements have been suggested in concordance to the augmentation of chronological and biological components (Asadi et al., 2018). However, Mendez-Villanueva et al. (2011) have conducted a study aimed to establish age-related differences in relation to sprint performance in U14 to U18 male soccer players. Thus, a possible influence of anthropometry (stature, body mass, fat-free mass), and biological maturation on performance in sprint-running qualities were examined suggesting that the physical qualities related to sprint, in young highly trained soccer players might be considered as related to qualitative adaptations in addition to maturation (Mendez-Villanueva et al., 2011).

On the other hand, the chronological age plays a key role in profiling young soccer players. This is a result of relative age effects observed when players born in the first quarter of the year, reported being faster than those born during the fourth quarter (Buchheit et al., 2010b). Importantly, aimed to analyze sprinting differences between U11 to U18 soccer players Mujika et al. (2009) showed that the repeated-sprint ability presented improvements progressively from the U11 to U15 groups, while no significant improvements were evident between the U15 to U18 groups. Additionally, it was reported that differences in sprint time were strongly correlated with differences in body mass and height (Mujika et al., 2009).

The importance of intermittent exercise capacity is supported by the strong relations between performance in field tests such as the Yo-Yo intermittent recovery test – level 1 (Yo-Yo IR1) and match running performance in soccer (Castagna et al., 2009; Palucci Vieira et al., 2019). Nonetheless, goalkeepers are usually the players with the lowest aerobic capacity, which is due to their different exercise demands compared to their outfield counterparts (Gil et al., 2007). Additionally, intermittent exercise capacity performance tended to differ related to the disparity experience and training time between elite and non-elite soccer players (Rebelo et al., 2013). On the other hand, when U13 to U18 highly trained soccer players were analyzed, Buchheit et al. (2010b) have reported that older players reached a greater maximal aerobic speed (MAS[2]), maximal sprinting speed (MSS[1]), anaerobic speed reserve (ASR[3]) and suppose better adaptations through lower heart rate parameter than younger players (Buchheit et al., 2010b). Thus, **table 1** presents some match-activities performed by U14 to U18 soccer players that shown evident improvements according to the augmentation of chronological age.

Table 1. Age-related differences in velocity profile in young soccer players.

Age-group	MAS ($km \cdot h^{-1}$)	MSS ($km \cdot h^{-1}$)	ASR ($km \cdot h^{-1}$)	HR_{max} ($beats \cdot min^{-1}$)
U14	15.2 ± 1.3	27.0 ± 1.7	11.7 ± 2.2	205 ± 8
U15	15.8 ± 1.1	28.7 ± 1.7	12.9 ± 1.9	201 ± 9
U16	16.5 ± 1.0	29.3 ± 1.4	12.7 ± 1.5	200 ± 6
U17	16.6 ± 1.0	30.9 ± 0.9	14.3 ± 1.0	198 ± 8
U18	17.2 ± 0.8	31.9 ± 1.7	14.7 ± 1.9	197 ± 9

ASR; anaerobic speed reserve, HR_{max}; heart rate max, MAS; maximal aerobic speed, MSS; maximal sprinting speed. Adapted from: Mendez-Villanueva, A., Buchheit, M., Simpson, B., & Bourdon, P. C. (2013). Match play intensity distribution in youth soccer. *International Journal of Sports Medicine, 34*(2), 101-110.

In summary, the profile of young soccer players has various aspects to be considered such as maturation stages, body composition, age and competitive level. In this context, it could be important to establish complementary training methods to match all aforementioned requirements of young soccer players.

2.3. Strength training in young soccer players

Strength training can be designed by manipulating several variables including the selected exercises, the exercises' order, intensity, volume, and rest between sets or repetitions (Fleck & Kraemer, 2014). However, muscular strength has a wide range of definitions, being those valid depending on the context and aims. For our purpose, strength could be understood as the condition required to execute any kind of motor skill, moreover, motor skills manifestations are dependent on sports specialism (Gomes & De Souza, 2008).

Strength also could be defined as the ability to exert force on external objects or exert large forces against gravity in order to manipulate the own body, manipulate the own body plus a sports implements (e.g., ball), and the interaction between those previous aspects and opponents in some sports such as soccer

[1]**MSS**: The best (fastest) 10-m split time normally during a 30 or 40-m sprint (Buchheit et al., 2012).

[2]**MAS:** The lowest running speed at which $V0_2max$ occurs (Swaby et al., 2016).
[3]**ASR:** The variation between MAS and MSS (Ortiz et al., 2018).

(Suchomel et al., 2016). Physiologically, strength could be defined as the capacity to exert muscle tension, considering aspects such as myosin filament amounts and their interaction with actin filaments and the muscle fiber types (Goldspink, 1992; González-Badillo, 2000). More importantly, resistance-based or strength training has been described as one of the most important aspects of soccer players performance (Hoff & Helgerud, 2004).

Giving a general strength training's evidence, Ahtiainen et al. (2004) have conducted a study in which the acute hormonal, neuromuscular responses and recovery in strength athletes versus nonathletes were analyzed. Concentrations on steroid hormones such as testosterone, showed significant increases after resistance-based training with high and medium loads (Ahtiainen et al., 2004). So far, the importance of strength training in soccer is evident with a crescent number of original articles per year published in last years. Therefore, strength training in soccer is viewed as an essential training component in different populations and research fields (Andersen et al., 1994; Faigenbaum & McFarland, 2016; Hoff & Helgerud, 2004; Suchomel et al., 2016). It is laudable, the fact that as research progresses, different methods have been designed to improve muscular strength and functional capacities in soccer players. Furthermore, the variety of adaptations in soccer players through the strength training previously described, it should be highlighted.

Morphological adaptations in young soccer players, have been reported in muscle groups such as the quadriceps. These adaptations were observed performing strength training in addition to regular soccer training (Spineti et al., 2016). At the same time, a greater number of training sessions per week has shown an association with higher strength gains after resistance training. Thus, the complementary resistance-based training should be considered as a recurrent method for improvements in physical performance (Beato et al., 2018).

Additionally, in young soccer players, changes in muscle size and strength levels, muscle fibers metabolism, improvements in muscular coordination and increased recruitment of motor units have been attributed largely to aspects such as neuronal adaptations through resistance-based strength training (Chelly et al., 2009). In the same context, Williams et al. (2011) have demonstrated that changes in soccer sprints, in an efficient way, also occur as a result of changes in muscle architecture, muscle-tendon, increased muscle mass, and by neural control and coordination enhancements (Williams et al., 2011).

Anyways, aspired to reach significant improvement in soccer context, different resistance-based methods have been described in specialized literature. Therefore, we must highlight methods such as traditional strength training (TST), that is widely supported as a fundamental element in athlete's training, since it has described performance enhancements in generic capacities independently of their sports specialisms (Peterson et al., 2004).

On the other hand, complex strength training (CST) that is tailored by a combination of weightlifting heavy-loads (80-90% of 1RM) exercises and sport-specific plyometric exercises, in the same workout, emphasized to promote the stretch-shortening cycle [SSC; (Freitas et al., 2017)]. Additionally, aimed to avoid confusion about terminologies, the previous method must be differentiated from the contrast training which has been defined as exercises that use high loads (e.g., 60 – 80% of the 1RM) and low loads (e.g., 30 – 50% of 1RM) in the same session, with both types of sets performed at maximum speed (Cormier et al., 2020).

2.3.1. Traditional strength training

TST method, normally involves high loads, few repetitions and maximal mobilization of force in the concentric mode. Usually, it has been described as a valid and effective method in the development of strength and related parameters (Hoff & Helgerud, 2004). For authors such as Raya and Sánchez (2018), TST could be associated with a deceleration of the load towards the end of the range of motion, with exercises such as squats and deadlift reported as part of this previous classification (Raya & Sánchez, 2018).

When TST method is performed, typically maximal strength is defined in terms of 1RM in which the main mechanisms based on the development of muscular strength are the hypertrophy and the neuromuscular adaptations (Hoff & Helgerud, 2004). However, in TST it has been ascertained intensity parameters for aspects such as maximal strength and hypertrophy, among others (Hoeger et al., 1990; Shimano et al., 2006).

Depending on the aspects such as level or experience, TST mainly aims to increase muscle size, strength, power, local muscular endurance, and it is used both for conditioned and injured athletes returning to practice. Specific adaptations can be targeted by manipulating different TST variables that could maximize the outcomes for better improvements. In this context, **table 2** briefly shows some TST program's characteristics.

Table 2. General characteristics of traditional strength training programs.

Training target	Reps	Sets	Intensity (%1RM)	Rest (min)
Hypertrophy	6 – 12	3 – 6	70 – 80	1 – 2
Maximal strength	1 – 6	3 – 5	> 80	> 3
Muscle power	1 – 6	3 – 6	50 – 70	2 – 3
Muscular endurance	10 – 20	2 – 4	40 – 70	1 – 2

1RM; One repetition maximum. Adapted from: Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: progression and exercise prescription. *Medicine & Science in Sports Exercise, 36*, 674-688.

In addition to previous recommendations, it has been suggested that the multiple-joint free weight or machine exercises have differential physiological and structural effects. Thus, it is recurrent to reach better performances on maximal strength through multiple-joint exercises (Kraemer & Ratamess, 2004).

Moreover, it is worth to mentioning an important study about TST in young soccer players. This was carried out by Chelly et al. (2009), where the effects of a be-weekly, 2-month TST program (85–100% of 1RM) on in-season period, in U18 soccer players were examined. Improvements in SJ, CMJ, 5 repeated jump test and 40-m sprint parameters after the intervention, without changes in muscle volume and cross-sectional area were reported (Chelly et al., 2009).

So far, Christou et al. (2006) conducted a study aimed to compare the effects of a TST program and the soccer-specific training on physical capacities in male young soccer players. TST was performed with loads of 55–80% of 1RM, twice a week for 16 weeks. Thus, 1RM-BP and leg press, SJ, CMJ, repeated jumps for 30 s, 10- and 30-m sprint, 5-m shuttle run and flexibility (seat and reach) were evaluated. The addition of TST to regular soccer training reported gains in all previously mentioned assessments. Furthermore, conclusions suggested the combination of soccer and resistance training programs for an overall development of the physical capacities in young soccer players (Christou et al., 2006).

Notwithstanding, Wong et al. (2010) have conducted a 12-weeks study in off-season period aimed to compare the effects of on-field TST in circuit form, adding to soccer-specific drills. The on-field strength training group obtained improvements on CMJ, 10- and 30-m sprint times, and prolonged exercise capacity. These findings suggested that TST strength training can be incorporated into regular soccer training without interference effects on aerobic capacity and with positive effects to improve explosive performances (Wong et al., 2010).

However, the TST method for soccer players has been suggested as a valid structure to develop and retain a high level of strength and power on soccer context, particularly for a great role in improving athletic performance by increasing different muscular aspects (Kraemer & Ratamess, 2004).

2.3.2. Plyometric training

Plyometric training is a method of physical conditioning that involves performing body-weight or light load exercises using the SSC muscle action (Markovic & Mikulic, 2010). The SSC describes an eccentric phase or stretch followed by an isometric transitional period (amortization phase), leading into an explosive concentric action, is therefore essential to many sporting movements such as running, and its performance depends on its efficient use within a movement skill (Turner & Jeffreys, 2010). Thus, the plyometric training aims is to increase the power output of subsequent movements, which is reached normally through the use of both natural elastic components of muscle and tendon in addition to the stretch reflex (Bedoya et al., 2015).

Agreeing with Markovic and Mikulic (2010), the SSC improves the ability of the neural and musculotendinous systems to produce maximal force in a shorter time. Furthermore, authors have mentioned that previous knowledge could be exemplified by simulating the use of plyometric training as a link between speed and strength (Markovic & Mikulic, 2010). At the same time, the plyometric training method has been frequently used for improving human neuromuscular function and enhancing performance in both explosive and endurance athletic specialisms.

Sports such as soccer may benefit from plyometric training since the explosive movements of this training method are similar to some demands placed on athletes performing specific soccer's movements (Meylan & Malatesta, 2009). So far, aspects such as age, training level, and the quality of movement skills have been suggested in the plyometric training structure. Additionally, it also has been suggested that a plyometric training program must consider the intensity in relation to the movement type. Thus, when the movements are related to jumps, previous aspects refer to components such as the jumps complexity and jumps height, among others. Furthermore, the volume considerations are normally related to the number of jumps allocated in a session training (Chu & Myer, 2016).

Considering the programing parameters such as intensity and volume, Ramirez-Campillo et al. (2015a) have conducted a 6-weeks research in young soccer players, performing 2 sessions per week, for a total of 2,160 bilateral, unilateral and combined jumps. Thus, all groups who performed plyometrics showed several muscular power and endurance performance measures improvements independent of the jump type. However, conclusive results reveal that the combination of unilateral and bilateral drills seems more advantageous to induce superior performance improvements (Ramirez-Campillo et al., 2015a).

Asadi et al. (2018) reported that the meaningful adaptations in jump performance through explosive training stimulus (as plyometric methods) and the capability of an athlete to generate maximal power have been attributed to the dependence mainly of the neuromuscular and mechanical athletes' properties on the musculoskeletal system (Asadi et al., 2018; Ramirez-Campillo et al., 2018).

Additionally, Peitz et al. (2018) have shown that the maturation directly affects the plyometric training outcomes regarding the greater adaptations in pre-PHV and post-PHV athletes. Thus, in terms of plyometric training, it also was reported that around PHV boys appear to respond with larger performance improvements in comparison with girls (Peitz et al., 2018).

However, the muscle actions induced by plyometric training exercises, particularly jumps, provide training stimuli for enhancing athletic performance especially when combined with resistance training. In this context, plyometric exercises are widely considered to reach positive adaptations in terms of power production and corresponding with soccer athletic performance (Ramirez-Campillo et al., 2018).

2.3.3. Complex strength training

It is worth mentioning that some of the first reports about the CST method, were based on anecdotal observations, literature publications, and conference presentations (Ebben, 2002). Thus, the CST has been known as an exercise that alternates high-loads (80 – 90% of 1RM) with biomechanically-similar plyometric exercises in the same workout inducing an initial potentiated neuromuscular state aimed to promote the SSC while replicating the movement demands of the specific sport (Ebben, 2002; Freitas et al., 2017). This method is supported by the supposition of a post-activation potentiation (PAP) of the neuromuscular system. The PAP is defined as a phenomenon by which the exerted muscle force is increased due to his previous contraction, additionally, it has been proposed as a possible mechanism explaining the benefits of CST method (Cormier et al., 2020).

In this context, one of the first evidence that support the CST method was based on the acute effect when comparing groups of with- and- without extra load in CMJ, preceded by a set of five repetition maximum BS. Results revealed 2.8% gains (improvement in jump performance; CMJ) (Young et al., 1998).

More importantly, the CST method, has shown positive effects on sprint, agility and vertical jump (e.g. through short-term, 6-weeks intervention) among elite young players (Alves et al., 2010). Also, comparing this method with plyometric training and resistance-based training, on male college players during 9-week, CST has shown to be adequate in short-term enhancements on strength, sprinting, agility, and vertical jump abilities (Brito et al., 2014). Nevertheless, it must be highlighted that previous CST-based interventions have been designed only on the vertical vectors (e.g. back squat, leg press, vertical jumps).

Nonetheless, Chatzinikolaou et al. (2018) have conducted a 5-weeks CST-based study with multi-joint power resistance exercises and Olympic-style lifts with 60 to 90% 1RM-BS and explosive exercises. Gains in strength and functional capacity in pre- and post-tests were observed in this study (Chatzinikolaou et al., 2018).

On the other hand, concerning to morphological adaptations in young professional soccer players, Spineti et al. (2016) have reported structural adaptations in muscle groups such as the quadriceps, when comparing strength training using CST and TST methods. Although authors described that results showed increases in muscular architecture through TST in comparison with CST, the functional capacities were better effective through CST method (Spineti et al., 2016).

It is worth to mentioning that most of the CST studies were conducted during the in-season period as well as presenting evaluations in neuromuscular domain and not in cardiorespiratory adaptations (excepting one; (Chatzinikolaou et al., 2018)). However, published CST researches, 2010-2020 in well-trained soccer players (14 – 21 yrs. old) are summarized in **table 3**.

Table 3. Complex strength training intervention studies in young professional soccer players published between 2010 and 2020.

Reference	Sample (n) / Age (yrs.)	Training intervention (Duration / Exercise)	Training adaptations
Alves et al. (2010)	17 / 17.4 ± 0.6	6 weeks / CST1 (one session/week: 1 set of 6-8 reps at 80-90% 1RM + explosive movements + RST) and CST2 (two sessions/week: same as previous + RST).	CST1 /CST2: ↑ T5, T15, SJ, ↔ CMJ
Brito et al. (2014)	12 / 17.4 ± 0.6	9 weeks / two sessions/week (1 set of 6 reps at 80-90% 1RM + skipping, vertical jumps, 60-cm DJ and 5-m sprint).	↑ 1RM: (BS, FPD, FPND, KED, KEND), Peak Torque, T20, T5, ↔ CMJ, SJ
Franco-Marquez et al. (2015)	20 / 14.7 ± 0.5	6 weeks / two sessions/week (2–3 sets; 4–8 reps at 45–60% 1RM + RST).	↑ $1RM_{est}$ -BS, CMJ, T10, T20, AVAL, FSVD 20, 30, 40 and 50%RM-BS
Spineti et al. (2016)	10 / 18.4 ± 0.4	12 weeks / three sessions/week (weightlifting 4–6 Reps at 60-100% PP-BS + sprint/jump).	↑ 1RM-BS, CMJ, RSA, ↔ Muscle arquitecture.
Hammami et al. (2017)	16 / 16 ± 0.5	8 weeks / two sessions/week (session1= 15 sets; 65reps; at 70 to 90% 1RM-BS and 15 sets; 65reps; at 90 to 70% 1RM-BS and 3 CMJ + sprint 15-m. Session2= 15 sets; 65reps; at 70 to 90%1RM + 3CMJ/sprint 15-m).	↑ T5, 10, 20, 30, 40, 1RM-BS, SJ, CMJ, RSA, COD, RCOD.
Kobal et al. (2017)	12 / 18.9 ± 0.6	8 weeks / two sessions/week (3-5 sets; 6-12reps; at 60-80% 1RM-BS + DJ 30-45cm).	↑ 1RM-BS, CMJ, T10, T20, ↔ COD
Rodriguez-Rosell et al. (2017)	43 / U-13 to U-17	6 weeks / two sessions/week (3 sets; 8-4 reps at 45-60% 1RM-BS + jumps and sprint 20-m).	↑ 1RM-BS, AVAL, CMJ, T10, T20
Chatzinikolaou et al. (2018)	12 / 14.2 ± 0.6	5 weeks / four sessions/week (13 Multi-joint power resistance exercises + Olympic-style lifts + plyometric and sprinting drills followed by 2-3 sets; 6-14reps; at increasing 60 to 90% 1RM-BS each week).	↔ Body Mass, Height BMI, % Body Fat ↑ IS knee flexors and extensors, COD, RSA, T30 1RM-BS, SJ, CMJ, DJ, Yo-Yo IR1.
Hammami et al. (2019)	14 / 15.8 ± 0.4	8 weeks / two sessions/week (15 sets; 65reps, at 70 to 90% and 90 to 70% 1RM-BS in the same	↑ FVT, 1RM-HS, EMG-VL, VM and RF

		session. + jumps; 4-10set; 7-10 reps at 0.50cm).	(during SJ), SJ, CMJ, LPP, T5, T40, COD.
Spineti et al. (2019)	10 / 18.4 ± 0.4	8 weeks / three session/week (high-power exercises 2 sets; 6reps; at 60-100% velocity of PP + high-velocity exercises).	↑T5, COD, SJ, ↔T10, T20, T30
Zghal et al. (2019)	14 / 14.5 ± 0.52	7 weeks / two sessions/week CST low-load high-velocity; 2 – 4 sets; 6 – reps) + plyometrics (30-60cm hurdle jumps)	↑ Knee extensors, RTD, CMJ, SJ, DJ, T5, ↔ COD, T10, T20

↔; No significative differences, ↑; Significative improvement, ↓; Significative decrements, 1RM; One repetition maximum, $1RM_{est}$; One repetition maximum estimation, 1RM-HS; One repetition maximum half squat, AVAL; Average velocity against loads, BP; Bench press, BS; Back squat, BHS; Back half Squat, BMI; Body mass index, COD; Change of direction, CMJ; Countermovement jump, CON; Control, CST; Complex strength training, DJ; Drop jump, EMG; Electromyographic, FSVD, Full Squat Velocity Development, FPD; Plantar flexion of dominant leg, FPND; Plantar flexion in non-dominant leg, FVT; Force velocity test, IS; Isokinetic strength, KED; Knee extension in dominant leg, KEND; Knee extension in non-dominant leg, LPP; Leg peak power, PP; peak power, RCOD; Repeat change of direction, RF; Rectus femoral, RST; regular soccer training, RSA; Repeat sprint ability, RTD, Rate of torque development, SJ; Squat jump, T5; 5-m sprint time, T10; 10-m sprint time, T15; 15-m sprint time, T20; 20-m sprint time, T30; 30-m sprint time, T40; 40-m spin time, VL; Vastus lateralis, VM; Vastus medialis, Yo-Yo IR1; Yo-Yo Intermittent recovery test level 1.

2.4. Confounding factors

Importantly, Bidaurrazaga-Letona et al. (2017) have suggested whether some performance aspects that have influenced or have become confounding factor such as age, maturation and body size in elite young soccer players. So far, those aspects and others like the adiposity, and maturity offset, have been reported as determinant performance components in elite young soccer players (Bidaurrazaga-Letona et al., 2017).

Moreover, terms such as pre-PHV, mid-PHV, and post-PHV refer to the maturity classification and are presented normally in different studies aimed to classify in a non-invasive way the maturity offset (Malina et al., 2000). Previous aspects are important because throughout the stages of maturation, some changes could appear or disappear in relation with performance after interventions within mature and immature individuals (Behringer et al., 2010). Also, this earlier aspect plays a key role influencing different functional capacities as well (Buchheit et al., 2014).

Current studies have reported that maturation plays a critical role in performance adaptations due to training in PHV stages (Lloyd & Oliver, 2012). However, few studies have specifically examined the interaction of training responses with maturation (Asadi et al., 2018; Lloyd et al., 2016). Moran et al., (2016) have described that, enhancements on jump ability in young soccer players related to PHV-stages could be exemplified as a “U” pattern, this essentially means that, when players are in pre-PHV improvements on jump ability are reached (upper initial “U” part). Mid-PHV stage is described as a period in which there is non-significant enhancements on previous quoted abilities (bottom middle “U” part). Finally, the post-PHV also showed gains in power capability and is understood as the upper final segment (Moran et al., 2016).

Furthermore, it also has been proposed that improvements in sprinting could be represented as linear gains, since enhancements are more evident with the pass of maturity stages (Asadi et al., 2018; Rumpf et al., 2015). In this context, Mendez-Villanueva et al. (2011) have described that sprint running performance in young soccer players depends on several factors mediated by growth and maturation, thus, effects on sprint are likely to be related to qualitative muscular adaptations that occur with maturation (Mendez-Villanueva et al., 2011).

Moreover, **figure 1** was designed based on previous knowledge and aimed to show graphically some previous suggestions.

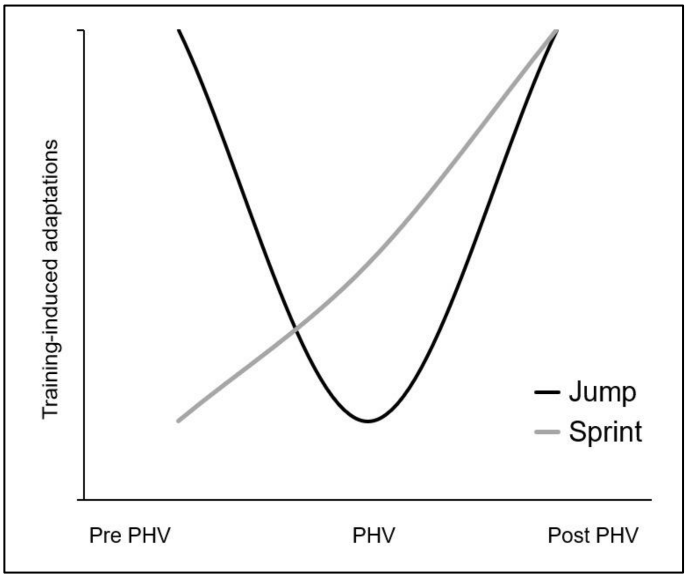


Figure 1. Improvements model related to peak height velocity stages.
Adapted from: Moran, J., Sandercock, G., Rumpf, M., & Parry, D. (2016). Variation in Responses to Sprint Training in Male Youth Athletes: A Meta-analysis. *International Journal of Sports Medicine, 38*(1), 1-11

Beyond biological maturation and other differential characteristics, another factor possibly affecting training adaptations could be the amount of exercise and its associated intensity, known as training load (TL; (Torbjørn et al., 2016)). In this context, quantifying TL must be fundamental to understand the stimulus that is applied to a human biological system. For example, there are evident differences between gym-based session, where all aspects could (and must be) pre-planned with previous knowledge about training schedule, whereas the field-based training has a high unpredictability, reverberating in aspect such as TL (Torbjørn et al., 2016). Therefore, it worth examining the dose-response between TL and training adaptations in soccer players.

Additionally, Gil-Rey et al., (2015) showed that accumulated TL in U18 soccer players during an in-season 9-weeks period considering training and match s-RPE in respiratory and muscular accumulated, have reported that correlations were most likely, very large and positive respectively with changes in aerobic fitness. Moreover, correlations between changes in CMJ and sprinting performance (i.e. 5 and 15 m) with accumulated TL and practice volume were possibly small and trivial (Akubat et al., 2012; Gil-Rey et al., 2015).

Chapter 3 – Problem statement, aims and hypotheses

3.1. Problem statement

Different resistance-based training methods such as CST, have shown positive effects on various expressions of strength and functional capacity (e.g. jumping, sprinting, and prolonged exercise capacity) in both adult and young professional soccer players (Bedoya et al., 2015; Silva et al., 2015). However, most studies have been conducted using resistance-based training methods only on the vertical force-vectors (e.g. back squat, leg press, vertical jump). In fact, only a few studies have integrated both vertical and horizontal vectors into a soccer's' training schedule, showing meaningful gains in elite male players (Abade et al., 2019; Ribeiro et al., 2020). Importantly, it must also be considered that resistance-based training studies, normally have been conducted during the competitive periods where training adaptations could be masked by the fact that players are already well-conditioned (Silva et al., 2016). Therefore, it was of authors' interest to understand the CST-induced effects on functional capacity after the preparatory period.

Furthermore, when studies are conducted in a real-context, where the control groups perform the training together with the experimental groups, it must be considered possible covariates affecting training adaptations such as inter-individual differences in biological maturation and training responses. In this context, few studies have examined either biological maturation or TL as covariates that affect training adaptations.

In summary, considering possible confounding factors inherent to soccer training context, there is no information available comparing TST and CST based on vertical and horizontal force-vectors, added to soccer-specific training, during the preparatory period in young professional soccer players.

3.2. Aims and hypotheses

This study aimed to compare the short-term effects of TST versus CST, added to regular soccer-specific training on maximal strength and functional capacity in U19 male professional soccer players during the preparatory period. A secondary purpose was to examine whether biological maturation and TL affect to training adaptations in maximal strength and functional capacities (e.g., jumping, sprinting, intermittent exercise capacity) in young professional soccer players.

We hypothesized that resistance-based strength training through TST or CST methods performed in vertical and horizontal force-vectors are effective approaches to enhance maximal strength and functional capacities in professional U19 soccer players.

Chapter 4 – Materials and methods

4.1. Design

To compare the effects of 4-week interventions of TST or CST, players were randomly assigned in two experimental groups; a TST group (*n*= 9; 4 defenders, 3 midfielders and 2 forwards), a CST group (n= 11; 4 defenders, 4 midfielders and 3 forwards) and control group (CON, *n*= 6; 3 defenders, 2 midfielders and 1 forward). The participants performed 4 familiarization sessions on the last days of the previous season in order to guaranty proper exercise technique and reduce injury risk.

Players were evaluated at the start and the end of a 4-week preparatory period training camp. Pre-test evaluations were conducted at the end of December (after the holiday's off-season period) and the post-test evaluation was carried out at the end of January before the first competitive match. On both occasions, evaluations were conducted on two consecutive days between the professional club facilities and the Institute of Applied Sciences, Physical Activity and Sport, by University of Guadalajara, Guadalajara, México.

The first day was organized as following: a standardized 12-min warm-up including general mobility and core exercises, estimation of one repetition maximum in back squat (1RM-BS) and bench press (1RM-BP), squat jump (SJ), and countermovement jump (CMJ). All previous evaluations were carried out in the Institute of Applied Sciences, Physical Activity and Sport. The second day took place in the club's facilities and was organized in the following order: a standardized 15-min warm-up consisting of dynamic stretching, running technique drills (e.g., skipping) and short (< 10m) sprints, then, the Illinois agility test (IAT), 30-m sprint and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) were performed.

All evaluations were carried out in the same conditions (week's days, schedule, facilities, players wearing the same team' clothes). Players were familiarized with the testing procedures as part of their team's routine in the previous season. The first evaluation day of both pre- and post-intervention was preceded by approximately 24-hours total rest. **Figure 2** illustrates the study design.

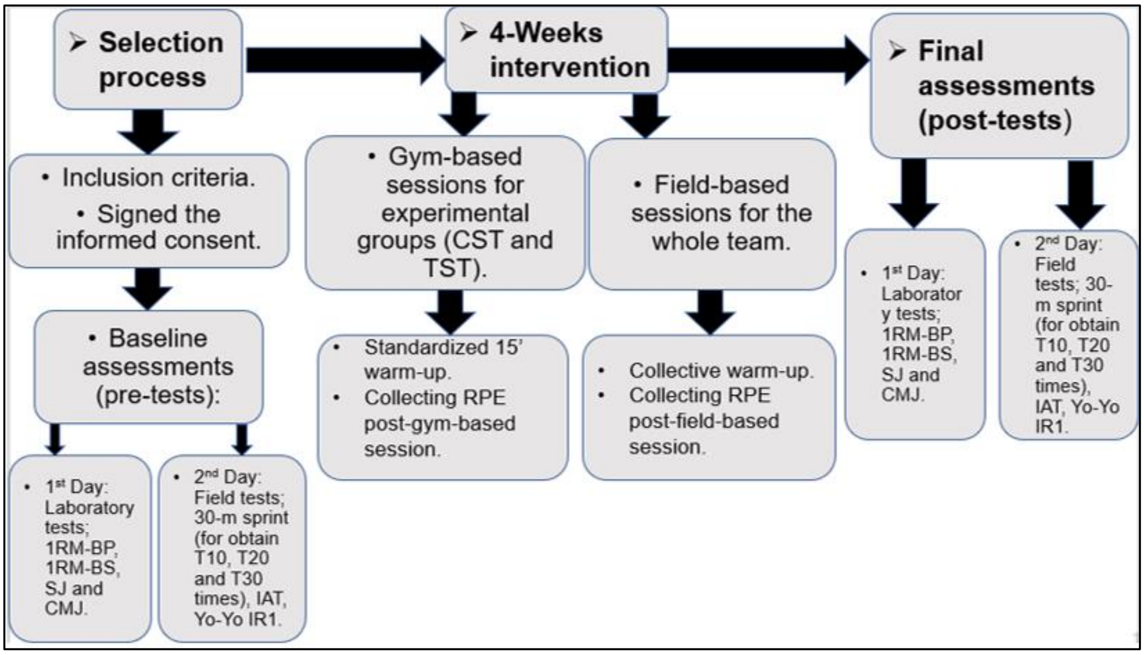


Figure 2. Study design.

1RM-BP; One repetition maximum bench press, 1RM-BS; One repetition maximum back squat, CMJ; Countermovement jump, CON; Control, CST; Complex strength training, IAT; Illinois agility test, RPE; Rating of perceived exertion, SJ; Squat jump, T10; Sprint 10-m, T20; Sprint 20-m, T30; Sprint 30-m, TST; Traditional strength training and Yo-Yo IR1; Yo-Yo- Intermittent recovery test level 1.

4.2. Participants

Originally, thirty-one outfield professional U19 soccer players were included in the study. After inclusion criteria: i) free of musculoskeletal injury or in the re-conditioning process, ii) minimum 6-month background in analytic (e.g. gym-based) strength and conditioning training, only twenty-six players (age = 17.38 ± 1.52 yrs.,) from the same team competing at National level in Mexico, participated in this research. Goalkeepers were excluded due to their different exercise demands compared to their outfield counterparts. All players were informed about the purpose and procedures of the study and provided an informed consent. In the case of the players being <18 years old, their parents or guardians were informed and provided written and verbal consent. Moreover, the study was approved by the Ethical Board of the Faculty of Sport, University of Porto, Portugal (CEFADE.07.2020; **Attachment 1**).

4.3. Covariates

Biological maturation and TL were considered as covariates. The biological maturation was calculated using the Mirwald et al. (2002) formula (*r*= 0.94 in relation to X-ray measurements) that is showed in **equation 1**.

$$\text{Yrs from the PHV} = -9.236 + (0.0002708) \times (\text{LL} \times \text{SH}) - (0.001663) \times (\text{CA} \times \text{LL}) + (0.007216) \times (\text{CA} \times \text{SH}) + (0.02292) \times \left(\frac{\text{BM}}{\text{Height}}\right)$$

Equation 1. Biological maturation.

where: LL is the leg length in cm, SH is the sitting height in cm, CA is the chronological age in years, BM is the body mass in kg, and height in cm.

Training volume was quantified using individual exposure time, which included either gym- and field-based training, warm-up protocols, and friendly matches. Exercise intensity was quantified using a Spanish version of the rating of perceived effort (RPE) a Borg' category ratio scale 1-10 (Foster et al., 2001), whose graphic is shown in **figure 3**. TL was described using the session-RPE method (s-RPE) which was obtained by the product of perception of effort and training volume (Foster, 1998). This method has shown a positive connection with objective training load based on heart rate measurement in young soccer players (*r*= 0.76; (Rodríguez-Marroyo & Antoñan, 2015)) and the players were familiarized with the questionnaire from the previous season. Gym and field training were quantified separately aimed to avoid confusion between TL after the gym session (associated to the intervention) and the possible variability of TL during regular soccer training session. Thus, only s-RPE from field session was entered as a covariate.

Score Puntuación	Please score how intense was your session today Por favor clasifique cuan intensa fue su sesión hoy
0	Nothing at all / Rest Nada / Reposo
1	Very very easy Muy muy ligero
2	Easy Ligero
3	Moderate Moderado
4	Somewhat hard Algo pesado
5	Hard Pesado
6	
7	Very hard Muy pesado
8	
9	
10	Maximal effort Esfuerzo máximo

Figure 3. Spanish version of the rate of perceived exertion questionnaire.

Adapted from: Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doleshal, P., & Dodge, C. (2001). A New Approach to Monitoring Exercise Training. *Journal of Strength & Conditioning Research, 15*(1), 109-115.

4.4. Testing

4.4.1. Maximal strength

Both one repetition maximum back squat (1RM-BS) and one repetition maximum bench press (1RM-BP) were carried out using an Olympic barbell, weight plates, two safety locks and sturdy squat rack with adjustable spotting bars (CAP, FC-CB8008, Houston, Tx, USA) on a flat solid surface, with two spotters positioned on the sides of the bar assisting the execution and one recorder. Our 1RM testing procedures were in line with the National Strength and Conditioning Association' guidelines (McGuigan, 2016). After, a warm-up in which, general mobility and like the testing procedures movements, were conducted.

The protocols were performed following a progressive load increase with a 3-5 min rest between each attempt. Moreover, the execution was based on the previous authors' criteria (Harmon et al., 2017). To keep injury risk at minimum, the final weight lifted within the 3-5 reps range was entered in an estimation equation for both BS and BP exercises (LeSuer et al., 1997; Whisehant et al., 2003).

$$1 \text{ RM (kg)} = \frac{\text{Weight lifted (kg)}}{1.0278 - (0.0278 \times \text{ Reps})}$$

Equation 2. Estimation of one maximum repetition in bench press and back squat.

Various authors have documented the validity and reliability of this equation in relation to the conventional 1RM method (*r*= 0.96–0.99) (LeSuer et al., 1997; Whisehant et al., 2003). Moreover, **figures 4** and **5** show graphically a brief view of the assessment implements and the procedure for 1RM-BP and 1RM-BS evaluations.

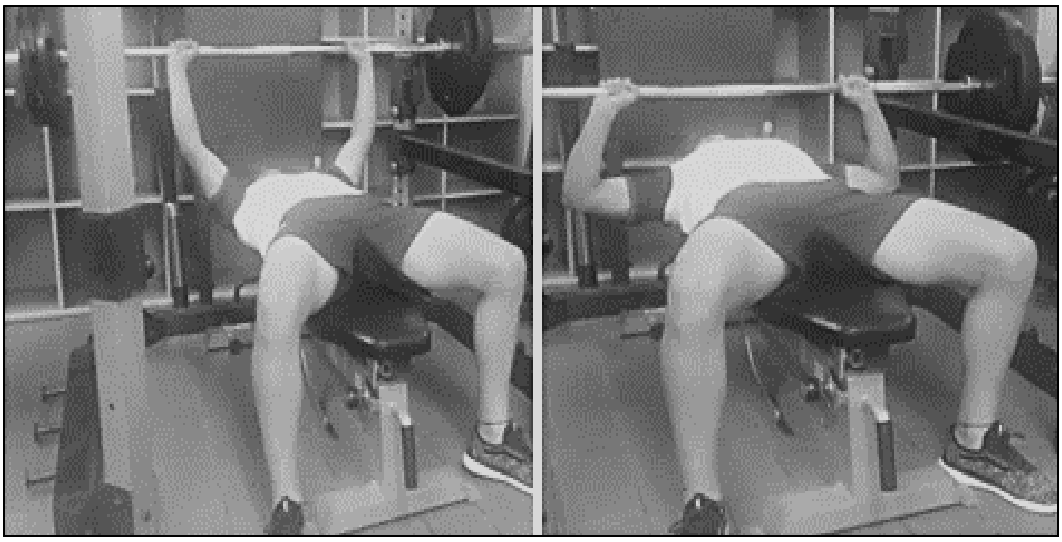


Figure 4. One repetition maximum bench press procedures.

Figure 5. One repetition maximum back squat procedures.

4.4.2. Vertical jump

The evaluation of both jump types (SJ and CMJ) were video-recorded at 240 frames per second using an iPhone-based App in an iPhone X (Apple Inc, Cupertino, Cal, U.S.A.). Videos were then imported to My Jump2 App (v.5.0.9; Balsalobre-Fernandez et al. (2015)). My Jump 2 was designed for analyzing vertical jumps to allow the calculation of the time (in milliseconds) between two frames selected by an independent user and subsequently to calculate the height of the SJ and CMJ. For jumps recording, the researcher lay prone on the ground with the iPhone X facing the participant (in the frontal plane), at ~1.5 m from them, and zooming in on participants' feet. The first frame in which both feet were off the ground (take-off phase) and subsequently, the first frame in which at least one foot was touching the ground (landing phase) were manually selected for height calculation (Balsalobre-Fernandez et al., 2015). **Figure 6** aimed to explain the previous process in a pictorially way.

This method has shown an almost perfect agreement with the force plate measurements (*r*= 0.99) and a good test re-test reliability (Intraclass correlation coefficient [ICC] = 0.80-0.99; CV [coefficient of variation]= 3.0%) to measure jump height (Balsalobre-Fernandez et al., 2015; Rago et al., 2018). Before the test, a standardized 6-min warm-up consisting of generic mobility exercises and two jump trials (one SJ and one CMJ) was carried out as well. Two attempts were performed for each jump type and the best trial (higher jump height) was retained for analysis.

Figure 6. Snapshots of My Jump2 App for vertical jump evaluation.
Where (A) is the take-off phase and (B) is landing phase.

4.4.3. Agility

The IAT was performed in order to evaluate the agility in a reliable and valid way (Hachana et al., 2013). The test was carried out allocating within four cones 9.2 × 7.2-m area and 4 marks allocated in the middle separated by 3.1 m each one. On command, the athlete sprints 9.20 m, turns, and returns diagonally to the starting line, then swerved in and out of 4 markers, completing two 9.20-m sprints to finish the agility course with two last 9.20-m runs, one in diagonally for then turn around and complete the test with a linear running (Hachana et al., 2013). **Figure 7** show the graphic description of this assessment.

8.

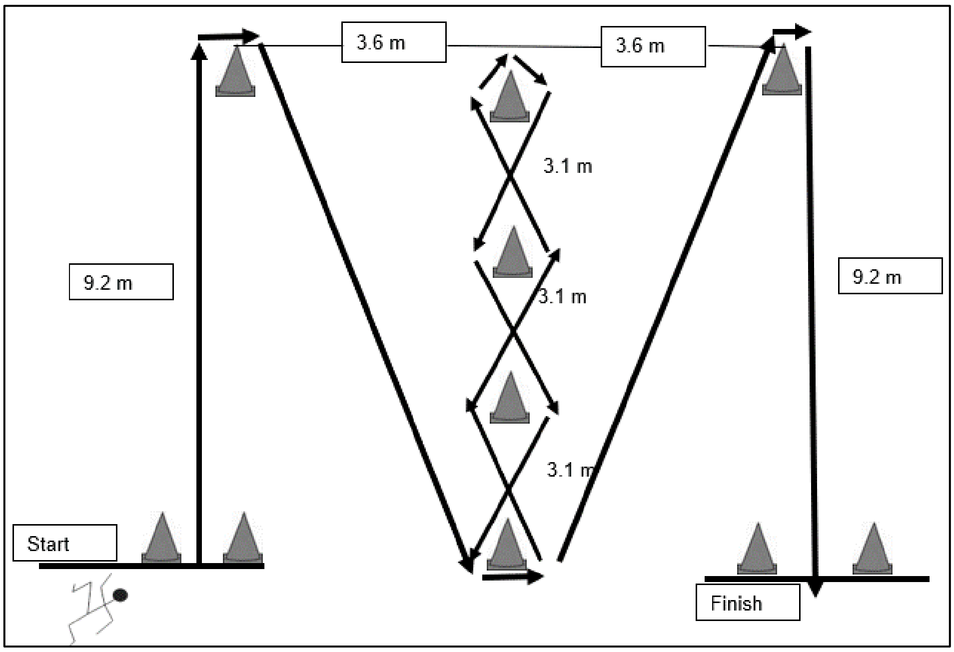


Figure 7. Illinois agility test.

Adapted from: Hachana, Y., Chaabene, H., Nabli, M., Attia, A., Moualhi, J., Farhat, N. & Elloumi, M. (2013). Test-Retest Reliability, Criterion-Related validity, And Minimal Detectable Change of The Illinois Agility Teste in Male Team Sport Athletes. *Journal of Strength & Conditioning Research, 27*(10), 2752-2759.

The IAT was video-recorded by 60 photograms per second using an iPhone model X (Apple Inc, Cupertino, Cal, U.S.A.). Videos were then imported to an iPhone-based CODTimer App (v.2.0; (Balsalobre-Fernandez et al., 2019)). About the CODTimer, vertical marks were allocated at the starting and ending lines, while the video was recorded from the side of the starting line. The total time in IAT was computed between two-time events that were manually selected by an independent previously-instructed user. The beginning of the test was considered as the first frame in which the participant crossed the starting point with his/her hips, whereas the end was considered as the first frame in which the participant's hips crossed the finishing point. This app has shown optimal validity in relation to timing gates measurements (*r* = 0.96) with an accuracy of 0.03 s (Balsalobre-Fernandez et al., 2019). Two attempts were performed with a rest of approximately 3 min, and the best trial (lower time) was retained for analysis. This aforementioned app and its procedures are explained in a graphic way in **figure 8**.

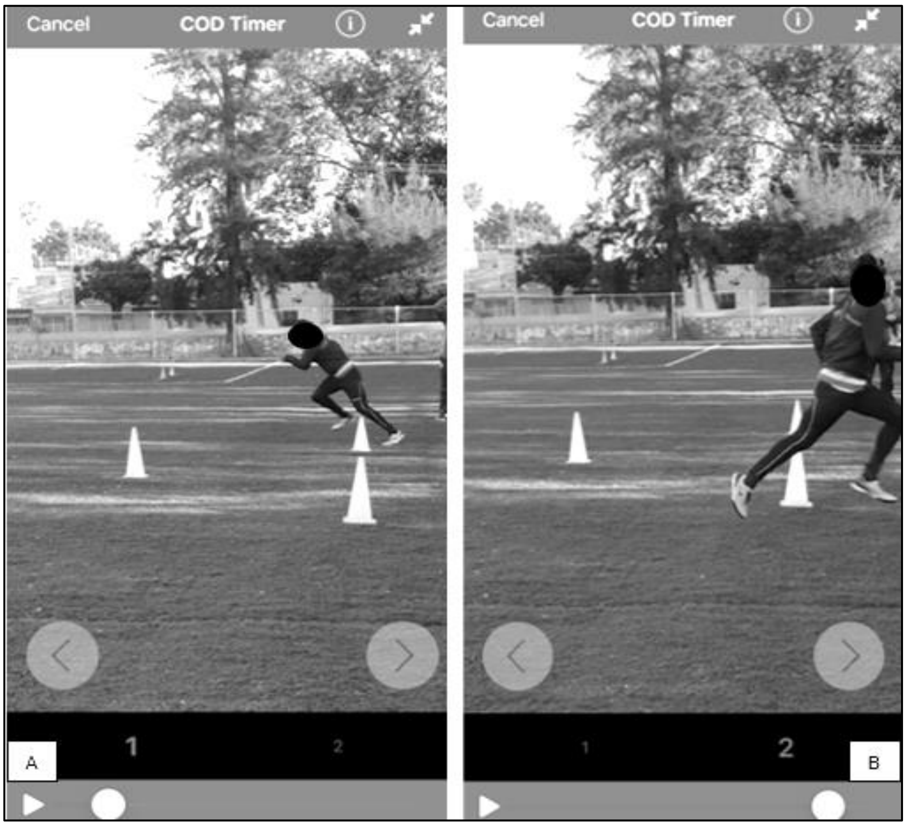


Figure 8. Snapshots of CODTimer app for agility evaluation.
Where (A) the cross of starting point and (B) is cross of finishing point.

4.4.4. Sprint

Sprint times over 10, 20, and 30-m (T10, T20, and T30) were recorded in a single linear all-out 30-m sprint using a high-speed video using a 60 frames per second in an iPhone model X (Apple Inc, Cupertino, Cal, U.S.A.). The camera was placed perpendicularly at 18-m in the sagittal plane of motion of the athletes in a fixed position. Then, videos were analyzed using MySprint App (v.1.10) as previously described by Romero-Franco et al. (2017). This method has shown an almost perfect correlation with timing gates measurements (r= 0.98–0.99) and has an accuracy of 0.007–0.015 s (Romero-Franco et al., 2017). Furthermore, previous procedures are described graphically in **figure 9**. The process to obtain T10, T20, and T30 results were based on frame's selection that was manually determined by an independent previously instructed user. Each partial time was considered as the first frame in which the participant crossed the points allocated every 10-m along to the 30-m linear sprint, whereas the end was considered as the first frame in which the participant crossed the finishing point. The explanation of previous procedure in a pictorially way is reported in **figure 10**. Two attempts were performed with approximately 5-min rest, and the best attempt (lower time) was retained for analyses. Thus, **figures 9 and 10** shows how the high-speed camera were allocated, the distances evaluated and MySprint app procedures.

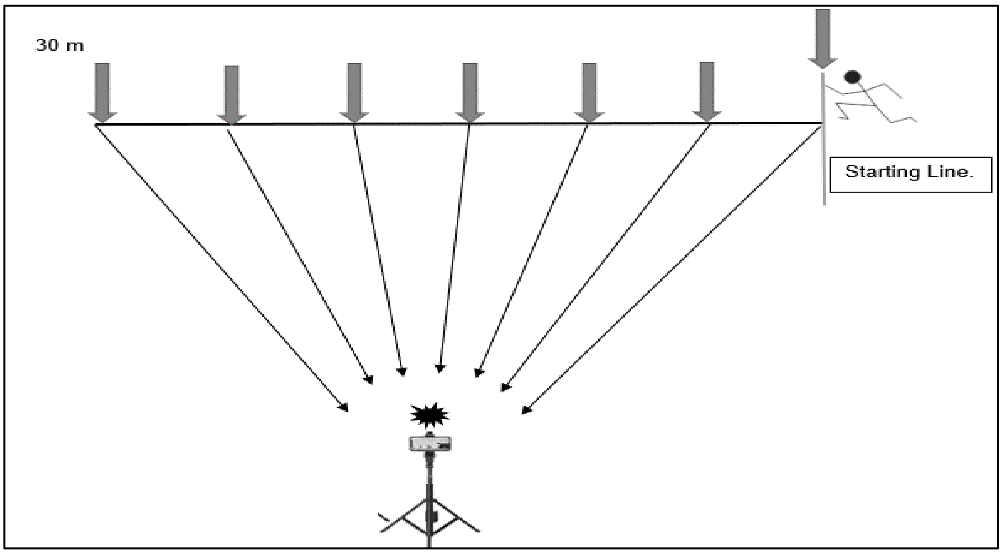


Figure 9. Sprint evaluation process using MySprint app.

Adapted from: Romero-Franco, N., Jiménez-Reyes, P., Castaño-Zambudio, A., Capelo-Ramirez, F., Rodriguez-Juan, J., González-Hernández, J., Toscano-Bendala, F., Cuadrado-Penafiel, V., & Balsalobre-Fernandez, C. (2017). Sprint performance and mechanical outputs computed with an iPhone app: Comparison with existing reference methods. *European Journal of Sport Science, 17*(4), 386-392.

Figure 10. Snapshots of MySprint app for sprint evaluation.

4.4.5. Intermittent exercise capacity

Intermittent exercise capacity was determined in the Yo-Yo IR1. The test consists of 2 × 20 m shuttle runs at increasing speeds, interspersed with a 10-s active recovery controlled by audio signals from a recording (Bangsbo et al., 2008). Thus, the test is also graphically described in **figure 11**.

When a player failed twice to cope with the speed imposed by the audio signal, the trial was interrupted with final distance covered retained for analysis. Performance in this test is largely correlated with direct measurements of maximal oxygen uptake and high-speed running covered during official soccer matches (*r*= 0.71–0.79) and has a good reliability (coefficient of variation =4.9% (Krustrup et al., 2003)).

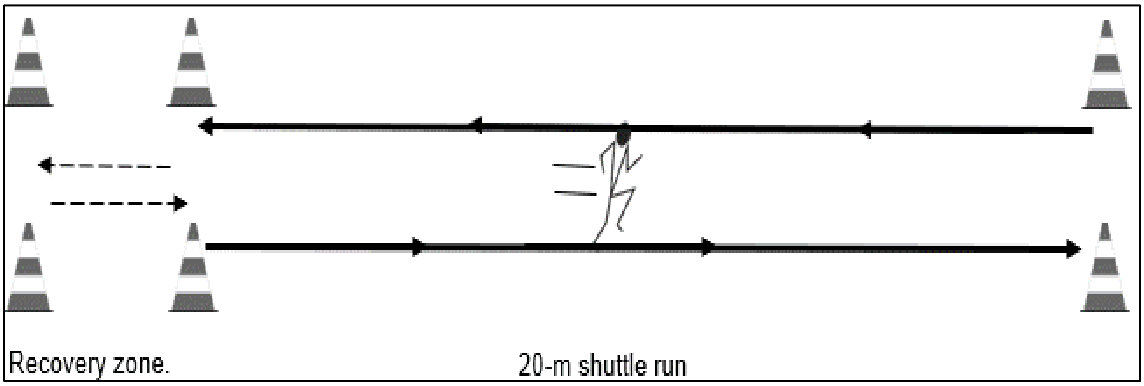


Figure 11. Yo-Yo Intermittent Recovery Test Level – 1 procedure.

4.5. Training Intervention

Different aspects must be considered in a resistance-based strength training context, among others, it has been reported that multiple-joint exercises are the best fit to increase muscular strength, hypertrophy, and power, maximizing performance (Kraemer & Ratamess, 2004). Thus, these exercises may be necessary for optimal gains. It was in this scenario that our intervention considered only that previous kind of exercise (multiple-joint).

The TST and CST groups performed two 60-min gym-based sessions per week before their regular soccer training, whereas the CON group only performed their regular soccer training. The gym-based sessions were separated by 48 hours of rest for both CST and TST groups. The training frequency (two times per week) was established based on different author's conclusions who described gains in strength and functional capacity (Alves et al., 2010; Brito et al., 2014). Both experimental training groups received a standardized 10-min warm-up mobility and ballistic exercises. It is worth to mentioning that the weekly program design and distribution of field-based training were carried out by the team staff. An example of this is allocated in **figure 12**.

Example of field-based training schedule of U19 professional male soccer players		
Day	**Content**	**Duration**
Monday	• Individual technical drills • Collective technical drills	90'
Tuesday	• Conditioning drills • Technical drills	90'
Wednesday	• Coordinative drills • Technical drills • Small-Sided games	90'
Thursday	• Tactical defensive drills • Tactical offensive drills • Tactical collective drills	90'
Friday	• Collective technical drills • Speed drills • Finishing drills	90'
Saturday	• Cognitive drills • 11vs11 drills	90'
Sunday	• Rest	

Figure 12. Field-based weekly content.

Thus, the present study involved multiple-joint exercises attending the specific musculoskeletal demands of soccer players (Hoff & Helgerud, 2004). Both TST and CST performed their routine coupon by 4 sets × 4 reps and intensity was set at 80-85% 1RM (established at the start of the preparatory period), separated by 3-min inter-set rest. Specifically, the TST group underwent only weight-based exercises, whereas the CST underwent weight-based exercises immediately followed by biomechanically similar plyometric movement.

A detailed description and illustration of the gym-training routine is reported in **figure 13**. Additionally, an example of the gym-based individual training program is allocated in the attachment section as **attachment 2**.

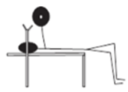
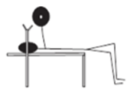
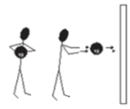
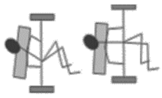
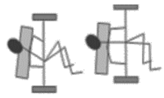
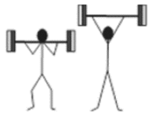
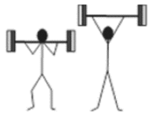
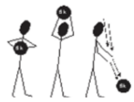
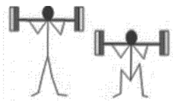
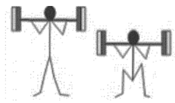
Order	Exercise	TST	CST	CON
Gym				
1	4 × 4 BP at 80-85% 1RM-BP			
	4 × 4 Medicine Ball Chest Throw (5 kg)			
2	4 × 4 Hip Trust at 80-85% 1RM-BS			
	4 × 4 horizontal jump (maximal effort)			
3	4 × 4 Push jerk at 60-65% 1RM-BP			
	4 × 4 Medicine Ball Slam (5 kg)			
4	4 × 4 BS at 80-85% 1RM-BS			
	4 × 4 Hurdle vertical jump (30 cm)			
Field				
5	RST			

Figure 13. Description of training routine (exercises' order and training load) of TST, CST and CON groups.

1RM; One repetition maximum, BP; Bench Press, BS, Back, RST; Regular soccer training.

4.6. Statistical analyses

Shapiro-Wilks tests were carried out aimed to analyze if all variables were normally distributed within each group and evaluation moment. Besides, first we tested the null hypothesis of no difference between groups in all baseline measures using multiple one-way analyses of variance (ANOVA). Second, also a two-way repeated-measures ANOVA was used on maximal strength and functional capacity variables. The independent variables included one between-subjects factor (training intervention) with three levels (TST, CST, and CON), and one within-subject factor (time) with two levels (pre- and post-intervention).

To examine the influence of training intervention on the development of our dependent variables, we used these ANOVAs to test the null hypothesis of no difference changes over time between groups (training intervention × time interaction). Third, a repeated-measures analysis of covariance (ANCOVA) was conducted to examine the possible influence of biological maturation and TL on training adaptations. To qualitatively interpret the magnitude of differences, effect sizes (*d*) and associated 95% confidence intervals (95%CIs) were classified as small (0.2–0.5), moderate (0.5–0.8) and large (>0.8) (Cohen, 1988). If the 95% CIs overlapped positive and negative values, the effect was deemed as unclear. Otherwise, the effect was deemed as the observed magnitude (Batterham & Hopkins, 2006).

Data was reported as mean (SD) for all variables and the level of statistical significance was set at $P \leq 0.05$. Data analyses were performed using Statistical Package for Social Science software (IBM SPSS, Version 25.0. Armonk, NY) and Microsoft Excel for Windows 10 (Microsoft Corp., Redmont, WA, USA).

Chapter 5 – Results

Table 4 shows the main characteristics of our sample, namely chronological age, maturity off-set (PHV stage), body mass and height.

Table 4. Characteristics of U19 professional male Mexican soccer players.

Variable	All players (n=26)	TST (n=9)	CST (n=11)	CON (n=6)
Age (yrs.)	17.38 (1.52)	17.44 (1.42)	18.00 (1.6)	16.17 (0.75)
Maturity offset (yrs.)	2.63 (1.03)	2.70 (1.16)	2.76 (1.10)	3.30 (0.77)
Height (m)	1.71 (0.05)	1.73 (0.08)	1.70 (0.04)	1.73 (0.03)
Body mass (kg)	66.20 (8.79)	69.32 (11.72)	66.50 (5.58)	60.95 (7.33)

CON; Control group, CST; Complex strength training, TST; Traditional strength training.

After performing a Shapiro-Wilks test, it was found that all variables were normally distributed within each group and evaluation moment (*P*>0.05). The results of the previous test are allocated into this section in **table 5**. Furthermore, the null hypothesis of no difference between groups in all baseline measures, through multiple one-way analyses of variance (ANOVA), and results of previous analyses are shown in **table 6.** Thus, the groups were performance balanced before the intervention, since all variables, in all groups, have showed non-differences (*P*>0.05).

Table 5. Shapiro-Wilks statistics normality check of fitness variables between groups and evaluation moment.

Variable	TST (n=9)		CST (n=11)		CON (n=6)	
	Pre	Post	Pre	Post	Pre	Post
1RM-BP	0.89	0.77	0.31	0.27	0.27	0.18
1RM-BS	0.23	0.54	0.86	0.71	0.68	0.76
CMJ	0.59	0.56	0.67	0.43	0.32	0.27
SJ	0.91	0.75	0.37	0.06	0.54	0.18
Illinois agility	0.13	0.63	0.15	0.62	0.11	0.55
10-m sprint time	0.10	0.41	0.40	0.79	0.20	0.83
20-m sprint time	0.25	0.74	0.18	0.14	0.35	0.88
30-m sprint time	0.16	0.92	0.06	0.22	0.32	0.81
Yo-Yo IR1	0.31	0.58	0.28	0.37	0.58	0.32

1RM-BP; One repetition maximum bench press, 1RM-BS; One repetition maximum back squat, CON; Control, CST; Complex strength training, CMJ; Countermovement jump, SJ; Squat jump, TST; Traditional strength training, Yo-Yo IR1; Yo-Yo- Intermittent recovery test level 1.

Table 6. Differences between groups before the training intervention.

Variable	TST (n=9)	CST (n=11)	CON (n=6)	Analysis of variance (*P*)
1RM-BS (kg)	101.73 (11.75)	107.20 (13.72)	91.99 (9.50)	0.06
1RM-BP (kg)	67.32 (10.09)	66.6133 (10.73)	59.80 (5.53)	0.29
CMJ (cm)	31.80 (3.83)	34.30 (6.96)	34.88 (3.06)	0.46
SJ (cm)	30.39 (2.80)	31.22 (5.91)	32.13 (3.27)	0.76
Illinois agility (s)	14.32 (0.42)	14.16 (0.30)	14.33 (0.33)	0.51
10-m sprint time (s)	1.87 (0.05)	1.87 (0.06)	1.87 (0.10)	0.99
20-m sprint time (s)	3.16 (0.06)	3.13 (0.08)	3.14 (0.12)	0.77
30-m sprint time (s)	4.40 (0.08)	4.34 (0.16)	4.34 (0.13)	0.63
Yo-Yo IR1 (m)	1637.7 (370.7)	1710 (506.6)	1410 (314.8)	0.38

1RM-BP; One repetition maximum bench press, 1RM-BS; One repetition maximum back squat, CON; Control, CST; Complex strength training, CMJ; Countermovement jump, SJ; Squat jump, TST; Traditional strength training, Yo-Yo IR1; Yo-Yo- Intermittent recovery test level.

5.1. Training adaptations.

It is important to mention that all players completed both pre- and post-interventions assessments (*n*=26). Both TST and CST group experienced moderate to large improvements in maximal strength (1RM-BP, *d*= 0.67 [0.29; 1.05] and 0.82 [0.41; 1.23]; 1RM-BS, *d*=0.91 [0.48; 1.32] and 0.85 [0.43; 1.30]; respectively; $P<0.05$), whereas no significant changes in 1RM were observed in the CON group ($P>0.05$). Moreover, the CST group experienced small-to-moderate improvements in SJ, CMJ, T10, T20, T30, and Yo-Yo IR1 performance (*d*= 0.73 [0.37; 1.10], 0.61 [0.26; 0.96], 0.57 [0.39; 1.20], 0.52 [0.13; 0.77], 0.43 [0.03; 0.71] and 0.55 [0.19; 0.91]; respectively; $P<0.05$).

CON group experienced moderate improvements in CMJ (*d*= 0.73 [0.21; 1.30]; $P=0.014$), while no one other functional capacity showed improvements. Additionally, TST group showed non-statistically significant changes in functional capacities such as jumping, sprinting and intermittent endurance ($P>0.05$), while non-significant changes in agility (IAT) were observed in all groups ($P>0.05$).

We examined the influence of training intervention on the development of our dependent variables. For this purpose, we tested the null hypothesis of no difference changes over time between groups (training intervention × time interaction). In this context, it was observed a significant moment × group interaction in maximal strength through 1RM-BP and 1RM-BS (*d* [95%CI] = 0.35 [0.04; 0.60 and 0.53 [0.18; 0.76], respectively; $P<0.05$). A detailed description of changes in maximal strength and functional capacities after the preparatory period is reported in **table 7**.

Table 7. Changes in maximal strength and functional capacity in U19 Mexican soccer players.

	TST (n=9)		CST (n=11)		CON (n=6)		Moment × Group Interaction	
Variable	Pre	Post	Pre	Post	Pre	Post	P	d (95% CIs)
1RM-BP (kg)	67.3 (10.09)	73.1 (11.94) ^{M}	66.6 (10.73)	77.7 (11.13) ^{L}	59.8 (5.53)	63.0 (6.37)	0.006	0.35 (0.11; 0.60)
1RM-BS (kg)	101.7 (11.75)	120.7 (16.26) ^{L}	107.2 (13.72)	124.8 (15.70) ^{L}	91.9 (9.50)	94.1 (8.86)	0.001	0.53 (0.24; 0.83)
SJ (cm)	30.3 (2.80)	31.6 (2.07)	31.2 (5.91)	34.4 (5.60) ^{M}	32.1 (3.27)	34.8 (4.54)	0.350	0.08 (-0.10; 0.27)
CMJ (cm)	31.8 (3.83)	34.5 (4.04)	34.3 (6.96)	38.3 (7.29) ^{M}	34.8 (3.06)	38.4 (3.43) ^{M}	0.690	0.03 (-0.13; 0.20)
Illinois Agility (s)	14.3 (0.42)	14.1 (0.51)	14.1 (0.30)	13.9 (0.41)	14.3 (0.33)	14.2 (0.39)	0.894	0.01 (-0.14; 0.16)
10-m sprint time (s)	1.87 (0.05)	1.90 (0.05)	1.87 (0.06)	1.81 (0.07) ^{M}	1.87 (0.10)	1.92 (0.05)	0.654	0.00 (-0.03; 0.04)
20-m sprint time (s)	3.16 (0.06)	3.14 (0.09)	3.13 (0.08)	3.08 (0.12) ^{M}	3.14 (0.12)	3.17 (0.07)	0.357	0.03 (-0.04; 0.11)
30-m sprint time (s)	4.40 (0.08)	4.40 (0.12)	4.35 (0.17)	4.30 (0.18) ^{S}	4.34 (0.13)	4.40 (0.10)	0.321	0.04 (-0.04; 0.12)
Yo-Yo IR1 (m)	1637 (370.7)	1733 (369.4)	1710 (506.6)	1863 (412.4) ^{M}	1410 (314.8)	1620 (165.4)	0.539	0.05 (-0.12; 0.22)

Superscript letters represent the effect sizes compared to pre-intervention (S; small, M; moderate and L; large; P< 0.05). 1RM-BP; One repetition maximum bench press; 1RM-BS; One repetition maximum back squat; CON, Control group; CST, complex strength training; CMJ; Countermovement jump; SJ, Squat jump; TST; traditional strength training ,Yo-Yo IR1; Yo-Yo- Intermittent recovery test level 1.

5.2. Covariates of training adaptations

5.2.1. Biological maturation

All players were above the PHV, (2.63 ± 1.03 yrs.), meaning that all players were in post-PHV stage. When adjusted for PHV, the TST group experienced small-to-moderate changes in SJ and T10 (*d*= 0.51 [0.06; 0.96] and 0.44 [0.01; 0.89]; *P*< 0.05; **Figure 15A**). However, all significant changes disappeared for the CST and CON group (*P*>0.05; **Figure 15B** and **15C**). Besides, moment × group interactions persisted for 1RM-BP and 1RM-BS (*d*= 0.35 [0.09; 0.60] and 0.54 [0.24; 0.83]; *P*<0.05) whereas a moment × group interaction appeared in T10 after PHV adjustment (*d*= 46 [0.21; 0.72] *P*= 0.001).

5.2.2. Training load

Irrespective of the medical assistance provided, no time-loss injuries were observed during the study, and a total of 758 individual TL observations were collected (598 after field sessions and 160 after gym sessions). No between-groups differences were observed in s-RPE neither after gym training nor field training (*P*> 0.05). An illustration of TL throughout the preparatory period is depicted in **figure 14**. In addition, when adjusted for s-RPE, TST group experienced moderate changes on performance in the Yo-Yo IR1 (*d*= 0.53 [0.09; 0.97]; *P*= 0.015; **figure 15A**).

Similar to what was observed regarding PHV, all significant changes disappeared for the CST and CON groups (*P*>0.05), as **figure 15B** and **15C** shows. Moment × group interactions persisted for 1RM-BP and 1RM-BS (*d*=0.33 [0.07; 0.58] and 0.55 [0.14; 0.96]; *P*<0.05) whereas a moment × group interaction appeared in T10 (*d*=42 [0.18; 0.68]; *P*=0.002). As a summary, an illustration of training adaptations adjusted for both covariates, biological maturation and TL, is reported in **figure 15**.

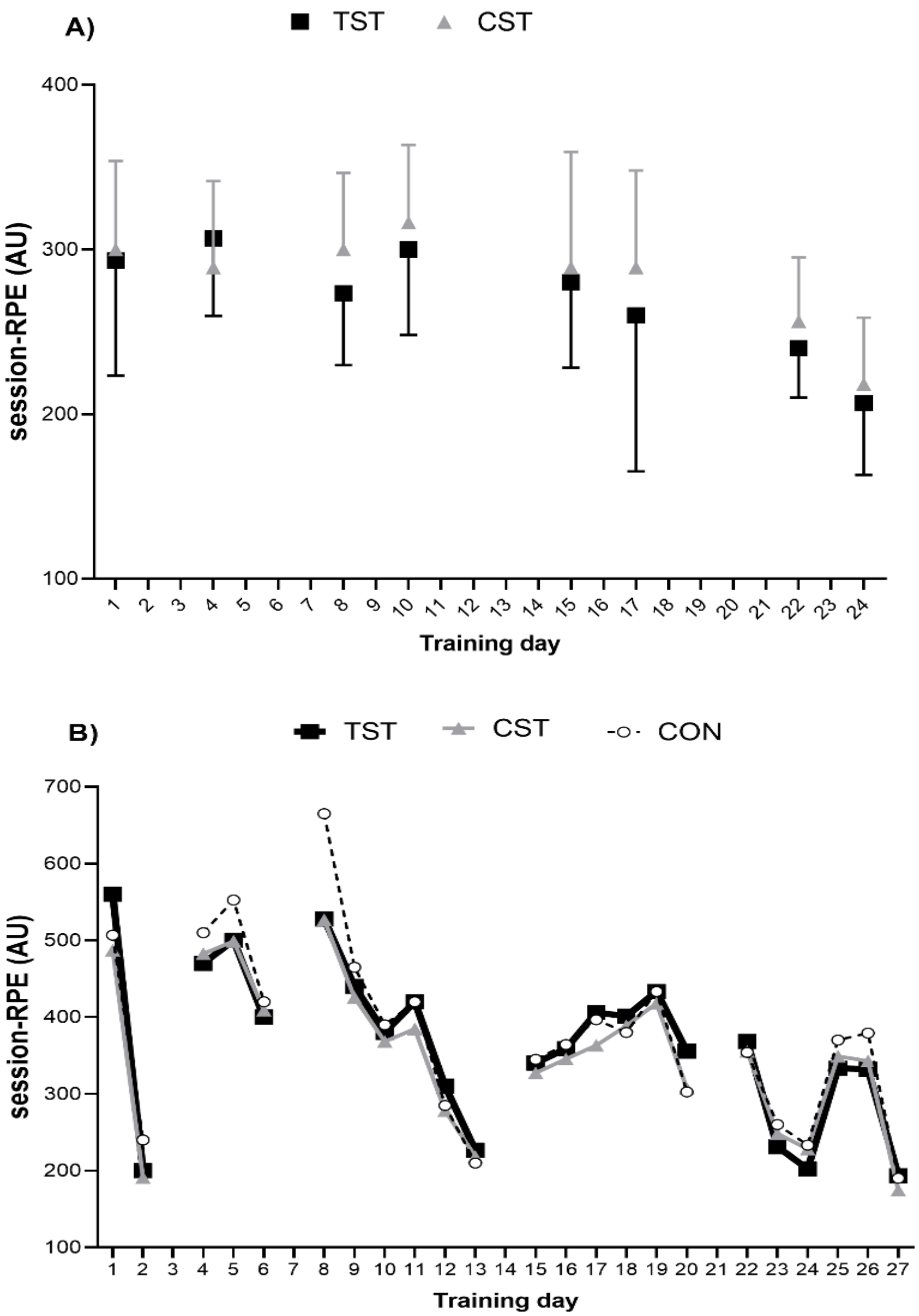


Figure 14. Daily training load during A) gym training, and B) regular soccer training.

CON; control group, CST; complex strength training, TST; traditional strength training. The gaps represent days off.

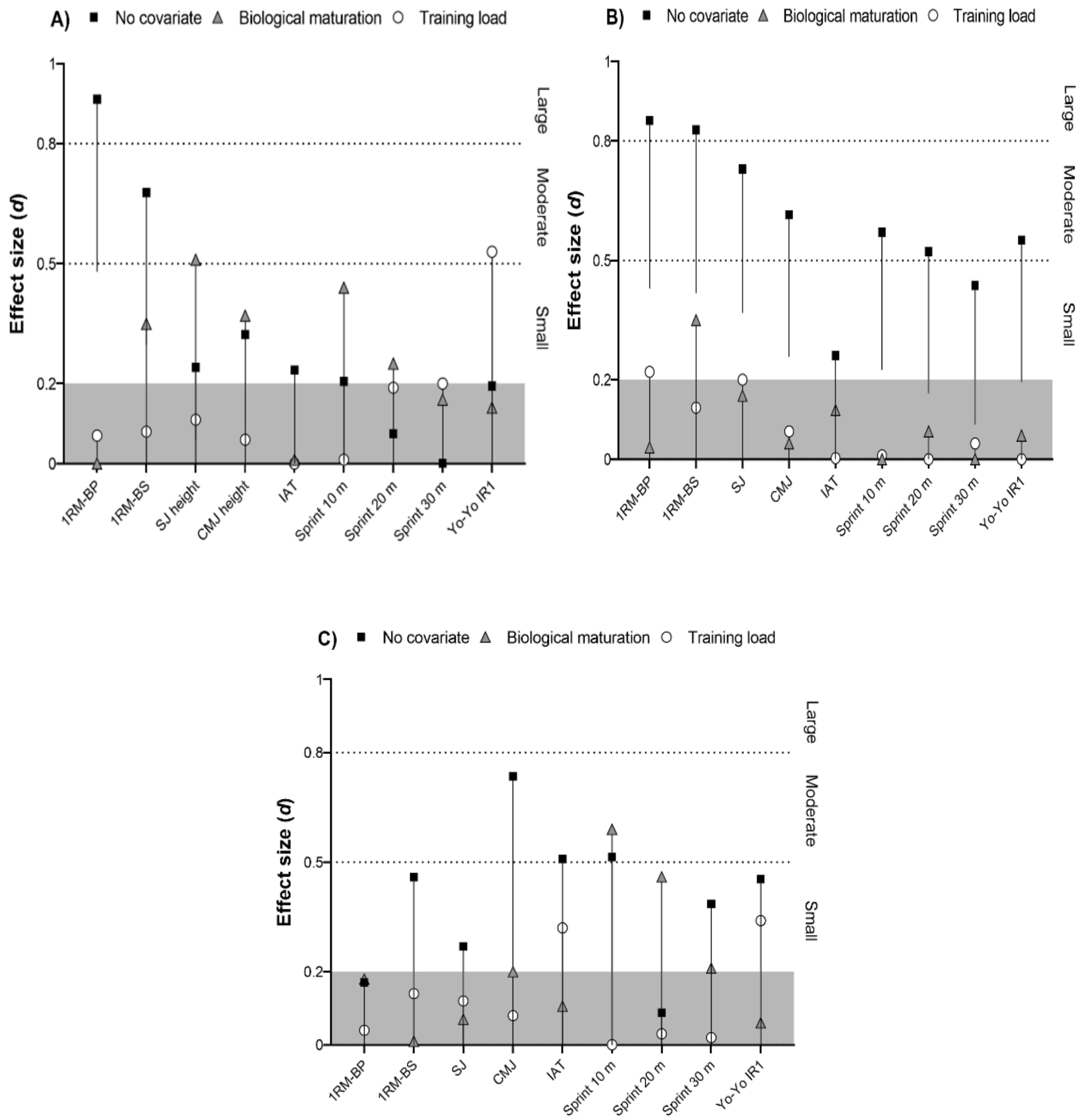


Figure 15. Magnitude of training adaptations adjusted for biological maturation and training load in the A) traditional strength training, B) complex strength training and C) control group.

1RM-BS; One repetition maximum back squat, 1RM-BP; One repetition maximum bench press, CMJ; Countermovement jump, IAT; Illinois agility test, SJ; Squat jump, Yo-Yo IR1; Yo-Yo-Intermittent recovery test level 1.

Chapter 6 – Discussion

6.1. Synthesis of main findings

This study examined the short-term (4 weeks) effects of TST versus CST incorporating vertical and horizontal force-vector exercises on maximal strength and functional capacity in professional young soccer players during the preparatory period. Both TST and CST interventions were equally effective to improve maximal strength. However, the CST was more effective than the TST to improve functional capacities such as jumping, sprinting, and prolonged exercise capacity, imposing identical perceived exertion. However, within-subject changes in maximal strength and functional capacity when adjusted for estimated biological maturation (e.g. age at PHV) and TL (e.g. s-RPE) were not statistically significant, suggesting that training adaptations are likely to be mediated by neuromuscular adaptations that occur with maturation and by global TL when performing complementary strength workout in addition to regular soccer training.

6.2. Training adaptations

6.2.1. Maximal strength

Both TST and CST groups experienced moderate to large improvements in maximal strength (1RM-BP, *d* =0.67 and 0.82; 1RM-BS, *d*=0.91 and 0.85) respectively, whereas no significant changes in 1RM were observed in the CON group *(view **Table 7**)*. Our findings could be partially explained by specific neural adaptations such as increases in motor unit recruitment, increases in coordination intra and inter-muscular and improvements on the involved muscle groups, as previously was reported after an upper- and- lower body resistance-based training in young soccer players (Chelly et al., 2009; Christou et al., 2006). The upper-body muscle strength is of importance in soccer for various actions, in particular throw-in. Moreover, running at high speed demands the simultaneous contralateral action of the arms and legs where muscles involved on BP exercise such as shoulders girdle, abductors of the scapula, and the elbow extensors protractors must help during running motion (Reilly, 2007). Concerning lower-body muscles, our study results are supported by Brito et al. (2014) findings, that showed significant gains in 1RM-BS after a 9-week on TST, CST and, plyometric training twice per week, in a U21 collegiate soccer players. Lower-body enhancement of maximal strength is important for performance in soccer players given its relationship with relevant functional capacities (r= 0.71–0.94; (Wisloff et al., 2004)). However, our results were expectable about this variable since only experimental groups performed strength resistance-based training during the preparatory period.

6.2.2. Vertical jump

The CST was moderately beneficial for jump ability parameters since it experienced small to moderate improvements in SJ and CMJ (d= 0.73 and 0.61, respectively; P<0.05) *(view **Table 7**).* This corroborates the small to moderate gains (η^2= 0.35 to 0.51) observed following a general strength and Olympic exercise combinations program during five weeks in U16 soccer players (Chatzinikolaou et al., 2018). However, our findings are in contrast to Alves et al. (2010) findings, which did not observe meaningful gains in CMJ following 6-week CST during the competitive period. This lack of agreements could possibly be attributed to the seasonal stage, where already-conditioned players during the competitive period may have masked the magnitude of training adaptations (Silva et al., 2015). It is worth to mentioning that in Alves et al. (2010), the intensity was set at 85% of 1-RM using exercises such as BS, calf raise, and leg extension. Thus, the disagreement between our findings and those of Alves et al. (2010) could be partially explained by biomechanical issues such as Olympic style and hip dominant exercise prescription since it might be speculated that hip thrust and push jerk exercises (adopted in our study), may be considered important components of a complementary strength training programs for soccer players.

A lack of positive TST-induced effects on CMJ was observed in our study. Meaningful changes could have been observed in alternative mechanical parameters of the CMJ during the ground contact (e.g. force at zero velocity), which have been deemed sensitive in detecting neuromuscular fatigue and training adaptations (Gathercole et al., 2015). Another possible explanation could be that CMJ adaptations were temporarily suppressed by neuromuscular fatigue induced by TST plus soccer training. Thus, significant adaptations in jump parameters in the TST could be observed later. On the other hand, the CON group who performed only regular soccer training without any complementary resistance-based training, obtained similar effects as the CST group on CMJ (*d*= 0.73; *P*=0.014) *(view **Table 7**).* These findings could be explained by the fact that players simply re-established their neuromuscular function (which possibly impaired following an off-season break (Silva et al., 2016)). Thus, detraining effects during off-season periods must be considered for a better understanding of effects of resistance-based strength training on jump ability performed during preparatory period.

6.2.3. Agility

In our study, although time in the IAT reduced in all groups after the preparatory period, these changes were not statistically significant *(P*>0.05*)*. In this context, De Hoyo et al. (2016) have conducted an 8-week strength training program in U19 soccer players that have considered TST, resisted sprints and plyometric training as intervention groups. Since non-significant results were observed in all groups, it was suggested that despite TST and Plyometric training seem to be effective for functional capacities improvement, agility might need another type of training stimulus to show positive effects (De Hoyo et al., 2016).

This is in contrast with findings in U17 soccer players undergoing TST or CST, with intensity set at 70-90% 1RM, twice per week during 8-week on competitive period that has showed small improvements in agility (time over 9-3-6-3-9 m with 180° turns; *d*=0.09 to 0.26) compared to regular soccer training (Hammami et al., 2018; 2017). However, it is worth to mentioning that in

Hammami et al. (2018) and Hammami et al. (2017) the experimental groups replaced a part of their standard training with strength training programs. This must be highlighted since the difference of the stimuli given by the strength and regular soccer training, as well as the difference that exists between the workload related to the training time spent by both, could overestimate previous results. Either way, the lack of statistically significant enhancements in agility in our study and the lack of agreement in different studies, could be partially attributed to the test selected as well.

Although the IAT has shown optimal reliability (Hachana et al., 2013), recent findings have questioned the ecological validity of various existent agility tests (e.g., IAT) in relation to the specific physical demands of soccer, with performance outcome possibly affected by specific test layout (one path with a given motor tasks sequence), rather than the actual player capacity (Rago et al., 2020). Therefore, the use of soccer-specific tests is recommended in future studies.

6.2.4. Sprint

Our study revealed small to moderate improvements in sprint times over 10, 20, and 30-m (*d*= 0.43 to 0.57) in players undergoing CST, but not in players undergoing TST and regular soccer training *(view **Table 7**)*. However, our results are supported by gains in T10 (η^2=0.310), following an 8-week program in U17 soccer players which strongly reflects the accelerative ability improvements (Hammami et al., 2018). Likewise, our findings are in concordance with Hammami et al. (2017) findings, where after an 8-week contrast training program in U17 soccer players, with intensity set at 70-90% of 1RM-BS, followed by explosive movements such as jumps, positive effects on T20 and T30 ($\eta^{2=}$0.13 to $\eta^{2=}$0.15) were reported (Hammami et al., 2017).

Moreover, although our variables consider different sprinting distances (T10, T20, T30), our results were corroborated by Alves et al. (2010) findings, where the effects of a 6-week CST training in U18 soccer players, resulted in improvements in sprint 5- and 15-m. This underlines the importance of prescribing resistance-based training programs with heavy-loads (80-90% 1RM) integrating SSC-exercises such as jumping or sprinting to enhance performance in actions requiring explosive efforts (Alves et al., 2010).

It has been reported that velocity increase to maximum running velocity appears to be more dependent on horizontal force production as opposed to vertical force production (Brughelli et al., 2011). In this context, our study is supported by a recent study that showed improvements in sprint (T10, T20, and T30), when heavy-load exercises followed by horizontal force-vector exercises such as hip thrust were performed, in comparison with vertical force-vector exercises like BS (Abade et al., 2019).

Importantly, take into consideration that when power and plyometric training were performed in horizontal vectors, small to moderate improvements in T10 and T30 were reported after a 7-week in-season intervention (Ribeiro et al., 2020) as well. Our findings are, however, in contrast to those of Spineti et al. (2019) who did not find meaningful changes in T10 and T30 after 8-week CST intervention, which could be due to the absence of horizontal vector exercises in the later program.

Regarding TST, in our study no significant changes were found in sprint variables. Similar results were found by Spineti et al. (2019) who did not find meaningful changes in T10 and T30 after an 8-week TST program with U19 soccer players (Spineti et al., 2019). This was also corroborated by findings reported after a 15-week TST intervention for U20 soccer players with a TST program performed three times per week, with loads of 4 – 15 RM, resulting in non-significant gains in sprint over 40-yards (*P= 0.72*; (Barbalho et al., 2018)). In sports such as soccer, the ability to produce high mechanical power output during jumps and sprints has been reported as an essential component of power-force-velocity profiling (Cronin & Hansen, 2005). This power-force-velocity profiling approach is based on force-velocity (F–V) and power–velocity relationships that characterizes the maximal mechanical capabilities of the lower limbs' neuromuscular system (Morin & Samozino, 2016). Thus, a possible explanation for our results could be that we did not consider the force– and power–velocity relationships, and mechanical effectiveness of sprint. Up until now, very limited information exists about force– and power–velocity adaptations in soccer players (Haugen et al., 2019).

6.2.5. Intermittent exercise capacity

The results obtained in our study suggest that only the CST program induced positive effects on performance in the Yo-Yo IR1 *(view **Table 7**)*, which could be partially explained by changes in SJ and CMJ. Indeed, Yo-Yo IR1 performance has been linked to SJ and CMJ abilities, indicating the meaningful neuromuscular contribution to achieve performance in this test (Castagna et al., 2006). We must note that performance in Yo-Yo IR1 test is largely correlated with direct measurements of maximal oxygen uptake and high-speed running covered during official soccer matches (r= 0.71–0.79; (Krustrup et al., 2003)).

Most of the studies with CST interventions, presented variables considering the neuromuscular domain and not the cardiorespiratory adaptations (excepting Chatzinikolaou et al. (2018)) as our study reported. We must take into consideration that our results are supported by different studies that reinforced the possibility to perform strength training in combination with endurance training or soccer-specific training, since enhancements on aerobic fitness do not negatively affect strength and power performance and additionally, does not provoke negative interference between those physical capacities (Karsten et al., 2016; Makhlouf et al., 2016; Wong et al., 2010). The importance of incorporate resistance training to enhance strength and power during soccer-specific activities has been suggested as an effective tool to reduce the possible seasonal alteration (decrease) of intermittent exercise capacity through greater muscle strength and power levels in soccer players (Silva et al., 2013).

6.3. Covariates

6.3.1. Biological maturation

When adjusted for biological maturation, moment × group interactions persisted for 1RM-BP and 1RM-BS indicating that, independently of the biological maturation, TST and CST likely induce positive effects of maximal strength. It is worth to underline that, as previously described, during maturation the natural development of performance occurs due to greater muscular size, increased limb length, changes of musculotendinous tissue, enhanced neural and motor development, and better movement quality and coordination (Lloyd et al., 2016). However, our sample showed gains in maximal strength dependent on training intervention since all players were into post-PHV stage *(view **Table 4**).* Thus, there are not just dependence on the theoretical increase of neural drive by the agonist muscles, changes in the muscle-tendon and improvements in intermuscular coordination attributed to PHV (Markovic & Mikulic, 2010), since the type of training stimulus was important for improvements in maximal strength.

On the other hand, when maturation was entered as a covariate, small to moderate changes in SJ and T10 were observed in TST group while all significant changes disappeared for the CST and CON group. A recent meta-analysis suggested that jump adaptative responses in accordance with biological maturation can be understood as a U-shaped curve, whereas gains in sprint are normally attained with the maturity stage showing a linear shape *(view **Figure 1**)*. Nevertheless, changes in SJ and T10 found in TST group after adjustments, indicated that those enhancements were dependent of maturation stage (PHV). This is supported by previous findings that reported gains in sprinting and jumping ability when strength training was added to regular soccer training of pre- and post- PHV soccer players (Lloyd et al., 2016). It is worth to mentioning that improvements in sprint (T10) and jump ability (SJ) after TST training program could be also partially explained by enhancements on hormonal profile provoked by post-PHV stages (Faigenbaum et al., 2013).

However, it has been suggested that substantial effects of maturity over and above other confounding variables such as anthropometrics are fundamental for age-related differences in aspects like speed qualities, changes in muscle architecture, and increases in muscle power since those are closely associated with the rise in circulating concentrations of testosterone and growth hormone from childhood to adolescence (Malina et al., 2004).

6.3.2. Training load

When adjusted for TL, TST induced moderate changes in performance in the Yo-Yo IR1 (d= 0.53). However, and similarly to PHV, all significant changes disappeared for the CST and CON group *(view* **Figure 15***)*. Thus, it can be suggested that training adaptations were TL (field-based training) dependent, either those that appeared in the TST group, as well as those that disappeared in the CST and CON groups. This is supported by factors affecting the s-RPE during field training such as the diversity of training drills (e.g. number of players, pitch dimensions), the specific tactical roles, and baseline fitness levels which lead to different physiological and perceptual demands (Campos-Vazquez et al., 2015; Rebelo et al., 2012). This is important since it is well-known that, when intervention studies are conducted in a real context, the control group perform regular soccer training together with the experimental groups.

Our results also showed that moment × group interactions persisted for 1RM-BP and 1RM-BS, indicating that maximal strength is non-dependent of TL parameters, whereas moment × group interactions appeared in T10 on the TST after TL adjustments. This last interaction (T10), possibly indicates that changes in acceleration capacity are dependent on the overall TL.

On the other hand, it must be highlighted that TST group did not improve performance in Yo-Yo IR1, which contrasts with findings following TL (field s-RPE) adjustment. Assuming that s-RPE is associated with objective methods of TL monitoring based on heart rate (Rodríguez-Marroyo & Antoñan, 2015), it is possible that training adaptations such as increases in the VO_{2max}, might be associated to the accumulated TL. Indeed, various studies have shown significant relationships between heart rate-based and TL (e.g. training impulse, time > 90% maximum heart rate) and gains in cardiorespiratory fitness in adult male soccer players during the preparatory period, (Campos-Vazquez et al., 2017; Castagna et al., 2011; 2013; Manzi et al., 2013).

So far, only one study has been conducted regarding the TL-training adaptations relationship in young soccer players (Akubat et al., 2012). However, our findings after TL adjustment corroborated suggestions from previous author studies, who described that a higher TL during the first competition weeks could be beneficial for physical components like the aerobic capacity in young soccer players (Akubat et al., 2012).

6.4. Strength training design

One aspect to consider to justify the lack of agreement between studies conducted with CST programs, as our study was, could be attributed to the seasonal stage, since most studies about CST were developed on competitive periods where strength training effects may be masked by an already-conditioned state of the players (Silva et al., 2015). In fact, our study was conducted in a 4-week pre-season (or preparatory) period and resulted in gains in almost all analyzed variables.

The training frequency adopted in our study (twice per week) was established based on different author’s conclusions that described improvements in maximal strength, physical capacity and increase in the player’s force production and muscle power-based actions during pre-season (Rønnestad et al., 2011; Silva et al., 2015). Additionally, our resistance-based strength program in both TST and CST groups, apparently was successful because, as it has been suggested, the free weight exercises, also known as multiple-joint exercises, allow to increase performance on maximal strength (Kraemer & Ratamess, 2004). Thus, CST and TST programs were provided with multiple-joint exercises and resulted in moderate to large improvements in maximal strength on BS and BP.

Furthermore, our strength training design also showed concordance with suggestions such as that maximal strength benefits are obtained by the use of heavy loads [>80% of 1RM; Schoenfeld et al. (2017)]. In this context, TST and CST, performed their routine couponed by 4 sets × 4 reps and intensity set at 80-85% of 1RM finding enhancements in maximal strength. It is worth to mentioning that our study presents agreement with suggestions such as that the combined strength/power training programs involving different movement patterns and an increased focus on soccer-specific power-based actions (e.g., CST) are preferred over traditional resistance exercises, not only due to their superior efficiency but also due to their ecological value (Silva et al., 2015).

The importance of horizontal force application while performing activities such as sprinting has been previously described by Rumpf et al. (2015), also showing a significant correlation between the horizontal force-vector and the maximum sprint velocity (r= 0.47; Brughelli et al. (2011). We must note that the use of horizontal force-vector exercises in our study was previously supported by studies performed for well-trained young soccer players, through TST methods (Abade et al., 2019), for high-level soccer players, with power-based and plyometric methods (Loturco et al., 2015; Ribeiro et al., 2020) and for collegiate athletes (Fitzpatrick et al., 2019). Nonetheless, our work underlined the importance not only of prescribing exercise in differential force-vectors such as hip thrust and BS, but also the relevance of performing resistance-based training integrating heavy loads and SSC stimulus. These must be aspects to consider in strength training programs for professional young soccer players.

6.5. Limitations

It is important to underline some limitations of this study. First, we have solely considered external measures of strength and functional capacity, based on weight lifted and parameters such as time and distance. Despite the validity and reliability of these assessments, we did not consider any physiological or direct measures such as blood samples to determine different hormone concentrations (e.g., serum testosterone, free testosterone, cortisol, growth hormone concentrations), which are important to explain training adaptations.

Secondly, training routines were individually tailored based on 1RM, which can change quite rapidly after only a few training sessions. Thus, the estimated value has a certain degree of error [2.27 kg below or 4.54 kg above the actual 1RM; (Whisehant et al., 2003)].

Thirdly, we adopted a TL measure based on a subjective perception, thus, neglecting the actual training responses observed during field training. In this regard, the use of wearable technology incorporating a global position systems and heart rate measurements has become a common practice among soccer practitioners (Wing, 2019).

Fourthly, results are based on a study a maximum of 9 – 16 players per group. So, it is difficult to make meaningful inferences about TST- and CST-induced adaptations. This could partially explain, for example, the lack of significant changes in agility in the experimental groups, or the intermittent exercise capacity in TST and CON groups.

6.6. Suggestions for future research

It is important to establish some areas or gaps to cover in future interventions. Since the peak performance of soccer players could report changes in different variables during the off-season period (Requena et al., 2017), detraining effects during off-season must be considered for a better understanding of strength and functional capacities improvements when resistance-based strength training is performed in pre-season.

The use of different soccer-specific agility tests must be considered in future studies since despite IAT has shown optimal reliability, recent findings have questioned the ecological validity of various existent agility tests (e.g., IAT; (Rago et al., 2020)), and this might influence the lack of agreement in agility for soccer players.

Since hip thrust and push jerk exercises (adopted in our study) may be considered as important components of complementary strength training programs for soccer players (Abade et al., 2019; Loturco et al., 2016), future studies might consider providing those exercises separately and comparing their effects in soccer players.

Attention must be paid to the fact that our study was aimed to measure the training adaptations, but we only considered evaluations through external measures. Thus, biochemical or physiological parameters must be considered in future research (Ascensão et al., 2008; Silva et al., 2013). Additionally, for a better comprehension of training responses, one interesting option could be the use of another non-invasive tool such as the wellness questionnaire to be administered before training sessions (Gastin et al., 2013).

Also, it could be beneficial to conduct a protocol in which CST method would be performed by players belonging to the three different PHV-maturation stages (pre, mid, and post), since the specialized literature has hypothesized that the improvements on strength and functional capacities depend on the maturity stage (Asadi et al., 2018; Malina et al., 2015).

Since CST appears to be the most beneficial method for maximal strength and functional capacity improvement, future research could separate exercises according to force-vector characteristics (vertical vs. horizontal). This aimed to figure out if CST, could be equally beneficial for enhancement in vertical horizontal vectors, separately.

In our study, the resistance-based training program was established considering intensities based on the resistance (kg). A more accurate way to design resistance-based programs, such as velocity-based training (relation between velocity and force used as a method to control load intensity) can be a valid and reliable alternative for exercise prescription (Conceicao et al., 2016; Gonzalez-Badillo & Sanchez-Medina, 2010).

Chapter 7 – Conclusions and practical applications

The main purpose of this study was to compare the effects of TST vs. CST on maximal strength and functional capacity in U19 professional soccer players during the preparatory period. A secondary purpose was to examine whether biological maturation and TL affect training adaptations.

This was the first research conducted in which CST method was carried out with resistance-based exercises performed on differential force-vectors, added to regular soccer training, two times per week during the preparatory period. CST was effective to improve maximal strength and functional capacities (sprint, jump and intermittent exercise capacity) in professional young soccer players.

Despite the fact that the TST program has shown improvements in maximal strength, it was not as effective as CST for functional capacity improvement. Significantly, the lack of improvements observed in the CON group (except for CMJ) underlines the need to incorporate complementary strength training within soccer players training sessions. Nevertheless, our results also suggested that the positive CST-induced functional effects were likely to be related to biological maturation and TL, in addition to the intervention itself. Contrarily, gains in maximal strength were independent of biological maturation and TL.

Overall, the following key points can be highlighted:

- Both TST and CST were effective for maximal strength improvement during the preparatory period;
- The CST was more effective than the TST for functional capacity improvement (sprint, jump and intermittent exercise capacity) showing a similar perceived exertion;
- Regular soccer training without complementary strength training might be not enough to promote training adaptations neither in maximal strength nor functional capacities in pre-season;

- CST-induced functional effects are likely to be related to biological maturation and TL, in addition to the efficacy of intervention itself;
- Gains in maximal strength were independent of biological maturation and TL.
- A 4-week training intervention during the preparatory period with resistance-based training apparently was enough to obtain improvements in maximal strength and functional capacities such as sprint, jump, and intermittent exercise capacity through CST method in young professional soccer players.

This findings can contribute to the knowledge about the CST-based training method; thus, the preceded results must be considered by strength and conditioning coaches or head coaches, who are involved with young professional soccer players.

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Attachments

Attachment 1. Ethical clearance.

U.PORTO
FACULDADE DE DESPORTO
UNIVERSIDADE DO PORTO

Comissão de Ética

Declaração

Para os devidos efeitos declara-se que o projeto CEFADE 07 2020 intitulado "Detraining and Retraining Effects of Traditional Strength Training Vs Complex Training On Physical Performance In Young Professional Soccer Players", submetido à Comissão de Ética da Faculdade de Desporto da Universidade do Porto por Carlos Efrain Miranda González foi aprovado, por ter em conta os requisitos éticos recomendados.

Porto, 29 de Abril de 2020

A Presidente da Comissão de Ética

Zélia Maria Matos de Almeida Roque Pinto

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Attachment 2. Example of an individual strength training program.

				Individual training program													Intensity: 80-85%RM				
Nome:						Body Mass:					Height:						Volume: 4 x 4 Reps.				
Exercise	%	100	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%
Squat		113	107	102	96.1	90.4	84.8	79.1	73.5	67.8	62.2	56.5	50.9	45.2	39.6	33.9	28.3	22.6	17	11.3	5.65
Kg x Set		1x4reps.=			2x4reps.=			3x4reps.=			4x4reps.=			Notes:							
Bench Press		73	69.4	65.7	62.1	58.4	54.8	51.1	47.5	43.8	40.2	36.5	32.9	29.2	25.6	21.9	18.3	14.6	11	7.3	3.65
Kg x Set		1x4reps.=			2x4reps.=			3x4reps.=			4x4reps.=			Notes:							
Hip Thrust		113	107	102	96.1	90.4	84.8	79.1	73.5	67.8	62.2	56.5	50.9	45.2	39.6	33.9	28.3	22.6	17	11.3	5.65
Kg x Set		1x4reps.=			2x4reps.=			3x4reps.=			4x4reps.=			Notes:							
Push Jerk		58	55.1	52.2	49.3	46.4	43.5	40.6	37.7	34.8	31.9	29	26.1	23.2	20.3	17.4	14.5	11.6	8.7	5.8	2.9
Kg x Set		1x4reps.=			2x4reps.=			3x4reps.=			4x4reps.=			Notes:							

Reps; Repetitions, RM; Repetition maximum.