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THESIS

Integration of Velocity Based Training as a tool to implement strength, power, and speed along with concurrent training methods in soccer players.

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ABSTRACT

Field based sports, such has soccer, expose players to a combination of both speed strength and power requisites supported by the metabolic systems that provide the energy to successfully respond to game demands achieving high-performance. Specific practice might not cover all endurance game demands, or in a homogeneous way, nor to all the strength power and speed abilities. Supplementing players with both endurance and resistance training might be of best practice. But some issues my raise when supplementing players with these types of training. One of the reasons this there are some flaws with traditional way to implement resisted training such the percentage-based training and RPE, so the need for a more reliable metric surged, where velocity-based training came to fill that gap. The other is that when combining both training modalities, concurrent training, inference effect occurs and strength and power related gains are diminished.

RESUMO

De forma geral, os desportos de campo, como o futebol, expoem os jogadores a terem determinados pré-requisitos de força, potência e velocidade suportados pelos sistemas metabólicos, que iram fornecer a energia necessária para mehor responder às demandas do jogo de modo a atingirem elevados níveis de performance. A prática específica, pode não atender a todas as demandas metabólicas do jogo, ou de uma forma homogênea, nem a todas as necessidades de força, potência e velocidade. Suplementar os jogadores com treino de resistência e corrida pode ser uma boa prática. Alguns problemas surgem quando suplementamos os jogadores com estas duas formas de treino. Um dos motivos é que existem algumas falhas no modo como é implementado o treino de força, sendo este baseado em percentagens e RPE, então a necessidade de uma métrica mais confiável surgiu, onde o treino baseado na velocidade veio para preencher essa lacuna. A outra é que, ao combinar os dois modos de treino, treino concorrente, ocorre o efeito de inferência e os ganhos relacionados à força e potência são diminuídos.

LIST OF ABREVIATIONS

RPE- Rate of Perceived Exertion

VBT- Velocity based training

F-V – Force Velocity

AVG-V – Average Velocity

P-V – Peak Velocity

L-V Load Velocity

P.F – Proximity to Failure

V.Loss – Velocity Loss

MVT – Minimum Velocity Threshold

HIIT – Hight Intensity Interval Training

SIT- Sprint Interval Training

RSS- Repeat Sprint Sequences

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CHAPTER 1 - GENERAL INTRODUCTION

1.1 GENERAL INTRODUCTION

The goal of every training session should be to optimize training adaptations, according to the stimulus imposed during that same session (SAID principle). Team sports game demands in general expose players to both endurance and explosive actions (Glassbrook, Doyle, Alderson, & Fuller, 2019; Ross, Gill, & Cronin, 2014; Stolen, Chamari, Castagna, & Wisloff, 2005; Vázquez-Guerrero, Ayala, Garcia, & Sampaio, 2020). Soccer is no different, where the game is played for at least 90 minutes at low-moderate pace interspaced with hight intensity actions (Orendurff, Walker, Jovanovic, Tulchin, et al., 2010; Stølen, Chamari, Castagna, & Wisløff, 2005).

It has been suggested that the amount of high- intensity actions can be a valid measure of physical performance in soccer (Mohr, Krustrup, & Bangsbo, 2003). Concomitant with the previous affirmation, players at higher competition level perform more high intensity running compared to their lower-level counterparts (J. Bangsbo, Nørregaard, & Thorsø, 1991; Ekblom, 1986). The study by Mohr and colleagues (Mohr et al., 2003) also concluded that top-players, not only performed more high-intensity running during the game, had better results in the yo-yo intermittent recovery test than lower level players, indicating also the improved ability to perform high intensity work repeatedly. Besides endurance, other physical qualities can have a positive impact on levelling players. For example, rate of force development, can be a differentiator between starters and non-starters (Gabbett, Kelly, Ralph, & Driscoll, 2009; Iguchi et al., 2011; Pincivero & Bompa, 2012; Young et al., 2005). In which strength power and rate of force development have a positive impact in this same type of actions (Suchomel, Nimphius, & Stone, 2016a)

For these reasons, training those physical qualities is of most importance to athletes better respond to the game demands and be successful. Exposing players to either repeated sprint demands, high intensity running or continuous lower intensity running can be a good way to supplement players besides the specific soccer training. Also, on the other hand, implementing a well round strength and power training covers the other side of the spectrum, that also has a impact on sport performance, providing players a well-rounded strength & conditioning training plan that covers all the needs to thrive in soccer.

The issue is that manly endurance interferes with strength and power adaptation, preventing the optimization of training adaptations(Dudley & Djamil, 1985; Ghosh, McBurney, & Robbins, 2010; Häkkinen et al., 2003a; Methenitis, 2018; Nader, 2006; Schumann & Rønnestad, 2019). To fully maximized the adaptations, some training strategies can be implemented such has nutrition protocols (Jeukendrup, 2004; Trexler, 2021), and timing between sessions or endurance modality. But, in a "real world" scenario it's not always possible to separate trainings 6 hours apart, or to have enough bicycles or other resources to a team has big has a soccer squad. For this reason, the goal of this thesis is to implement velocity-based training as tool to help guide practitioners to maximized both training adaptions accordingly to the stimulus provided.

1.2 STRENGHT TRAINING IN SOCCER

Strength can be one of the underpinning characteristics that can potentiate overall power and rate of force development, being the latter two considered to be of the most important in sports performance (Suchomel, Nimphius, & Stone, 2016b). Soccer is no exception, where players are expose to both low to moderate intensity actions but also to high intensity and max effort actions (Orendurff, Walker, Jovanovic, L. Tulchin, et al., 2010), such has sprints, jumps and duels. Also, this high intensity actions are in general, the ones that can change the game outcome (Dellal et al., 2011).

That being, it's reasonable to believe that improvements in physical qualities that can be transferable to soccer demands will probably improve players performance. In fact, strength training can increase both endurance performance, manly by improving running economy (Balsalobre-Fernández, Santos-Concejero, & Grivas, 2016; Blagrove, Howatson, & Hayes, 2018; Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999; Vikmoen, Rønnestad, Ellefsen, & Raastad, 2017; Vorup et al., 2016) but also and explosive actions (Aagaard, 2010; Alcaraz, Carlos-Vivas, Oponjuru, & Martínez-Rodríguez, 2018; Galiano, Pareja-Blanco, Hidalgo de Mora, & Sáez de Villarreal, 2020; Lahti et al., 2020; J.-B. Morin et al., 2017; Suchomel et al., 2016b).

Running economy can be defined has the energy/oxygen cost for a given sub-maximal velocity, and it can be affected by force characteristics and the ability to utilise the stretch-shortening cycle (Blagrove et al., 2018). For example, strength training has the ability to increase force production by several means (Grgic, Schoenfeld, & Latella, 2019; Reggiani & Schiaffino, 2020). Therefore, if an athlete increases his absolute strength, for a given running speed peak vertical forces will be relatively lower intensity compared to when it was weaker, thus reducing the necessity to activate higher threshold motor units (Balsalobre-Fernández et al., 2016).

Another benefit of implementing a strength training program into athletes routine is to diminishing the injury risk (Case, Knudson, & Downey, 2020; Cuthbert et al., 2020; Zwolski, Quatman-Yates, & Paterno, 2017) also positively impacting team success (Djaoui, Haddad, Chamari, & Dellal, 2017; Eirale, Tol, Farooq, Smiley, & Chalabi, 2013).(Blagrove et al., 2018). In a systematic reviewed and meta-analysis carried out by Laueresen and colleagues (Lauersen, Andersen, & Andersen, 2018) concluded that, training programmes that included resistance training in their injury prevention programmes, had on average a 66% reduction compared to other that didn’t include resistance training. Injury occurs when the force applied overcomes the structural ability that a body tissue has, to maintain his integrity, at a given moment. There are several ways by which strength training can diminish the injury risk one of which is by increasing the structural strength of tendons, ligaments, connective tissue and cartilage (Fleck & Falkel, 1986). Other is the increase in muscle stiffness, associated with strength gains and reduction in electro mechanical delay, that can provide a better stabilization for the joint (Blackburn, Guskiewicz, Petschauer, & Prentice, 2000), possibly preventing it from excessive and undesired movements.

The way strength training should be implemented alongside specific training, depends on many factors such has calendar, individual necessities, and readiness at the time of training and the fatigue induced by the resistance training itself. There are various form of resistance training depending on the main focus of stimulus, that is, if training purely for hypertrophy, strength, power or speed. Has seen in previous literature, training volume is an important pre-requisite for gains ins muscle mass (Schoenfeld et al., 2019) but also carries more muscle fatigue (F. Pareja-Blanco et al., 2017; J. Weakley et al., 2021; J. Weakley, McLaren, et al., 2020). Has for purely strength power and speed outcomes volume does not need to be higher has in hypertrophy, and accumulated fatigue during the set is not necessary to increase strength outcomes, might even have a detrimental effect on speed and power. (Galiano et al., 2020; F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco, Sánchez-Medina, Suárez-Arrones, & González-Badillo, 2017; Sanchez-Medina & González-Suárez, 2009; J. Weakley et al., 2021; J. Weakley, McLaren, et al., 2020). But an important note is that when training for strength, even though there is not a necessity to accumulate fatigue during the set, to the nature of strength training (higher loads/lower repetition/velocity) athletes train already relatively close to failure (J. J. González-Badillo & Sánchez-Medina, 2010), and that might cause more overall fatigue and/or muscle soreness compared to speed and power training, but further research on whether the proximity to failure by its self is a proxy to fatigue for the same velocity loss/rate of perceived exertion.

That being, practitioners should allocate and/or diminish frequency of the more stressful/fatiguing sessions further away from official games, were fatigue might impair their performance during the session. Whereas during the off-season apply the more stressful/fatiguing session but also provide a more structural basis for the upcoming season (J. Weakley et al., 2021).

1.3 VELOCITY BASED TRAINING

Strength can be manifested in various forms, and categorized along the force-velocity curve as maximum strength, strength-speed, peak power, speed-strength and maximum speed (Walker, 2017). The traditional way of prescribing training loads was through the assessment of one repetition maximum (1RM) and there after prescribing the desired percentage of that same 1RM (eg. 5x5 @70%) (J. J. S. Weakley et al., 2017). Also a possible way to control/prescribe training loads is by utilization of an subjective measurement of performance/exertion such has rate of perceived exertion or repetitions in reserve (Foster et al., 2001; Zourdos et al., 2016) which, similar to percentage based training has is flaws (Cooke et al., 2019a; Hackett, Cobley, Davies, Michael, & Halaki, 2017a; Haddad et al., 2013; Haddad, Padulo, & Chamari, 2014; Zourdos et al., 2021) and will be discussed along this chapter. Therefore, emerged the necessity to develop a more objective and precise measurement tool, such has VBT (Banyard, Nosaka, Vernon, & Haff, 2018; Banyard, Tufano, Jose, Thompson, & Nosaka, 2019).

1.3.1 TRACK PROGRESSION

VBT can provide various metrics for training outcomes being one of them simply the speed at which the bar is moving through space (J. Weakley et al., 2021) Alongside RPE, VBT can also be used to track progression (J. Weakley et al., 2021), that being for example, if for a fixed load and reps, avg. velocity (AVG-V) or peak velocity (P-V) increases (RPE decreases), that might be expected that at least in that spectrum of the F-V Curve there were improvements. Another way can be done is, for a fixed AVG-V, P-V or RPE, there is a need to increase in load (implement velocity loss due to external load). Also, for a fixed number of reps at a given load, there is less AVG-V or P-V velocity loss (due to increase in fatigue through the set and/or overall exercise).

Although RPE is a much cheaper, and reliable tool (Haddad, Stylianides, Djaoui, Dellal, & Chamari, 2017). But has its downsides when accounting for tracking exercise progression(Haddad et al., 2013, 2014). When performing the more power speed-strength or speed exercises, in general their performed further away from failure, making RPE less reliable (Hackett, Cobley, Davies, Michael, & Halaki, 2017b). While the usage of velocity metrics can detect changes, when meaningful, that can help practitioners better track improvements in exercises, by adding VBT has a tool to track progression.

1.3.2 MOTIVATION AND COMPETITION

It is known that feedback can improve athlete's performance acutely (Ramirez, Núñez, Lancho, Poblador, & Lancho, 2015; J. J. S. Weakley et al., 2019; J. Weakley et al., 2021). VBT can also provide a mean to augment performance increase during training (J. Weakley, Wilson, et al., 2020). Whether by creating a competition (within or between athletes). Also, this results my carry over in the long-term, Weakly (W. J et al., 2019) were greater increases in jump height, 10 and 20-m sprint, 3 RM Squat and Bench Press over a for 4-week mesocycle.

1.3.3 LOAD PRESCRIPTION

1.3.3.1 TRADITIONAL STRENGTH TRAINING

VBT can help practitioners determine the load to impose to the athlete at a given exercise according to a general Load-Velocity (L-V) relationship or an individual L-V relationship proposed by Gonzalez Badillo and Sanchez-Medina (J. J. González-Badillo & Sánchez-Medina, 2010), also possibly understanding better the proximity to failure (PF) during sets according to a standardize mean velocity threshold (MVT) for the respective exercise or the individual MVT if the individual L-V profile was taken previously.

MVT or V1RM corresponds to the velocity at which 1RM is performed with a nearly perfect linear relationship between velocity and intensity (J. J. González-Badillo & Sánchez-Medina, 2010) and varies according to the exercise itself (Balsalobre-Fernández, García-Ramos, & Jiménez-Reyes, 2017; Banyard, Nosaka, & Haff, 2017; García-Ramos et al., 2019).

There are several methods to access an individual L-V profile for a given exercise (J. Weakley et al., 2021). On is by accessing the individual 1RM e the respective MVT/V1RM, allow him to recover at least 24 hours, and then use a incremental loading test with 3 repetitions at 20-40 and 60% and then one repetitions at 80 and 90% allowing 2’ rest between sets. Record the best speed at each percentage and then apply the regression equation (J. Weakley et al., 2021)

Whereas prescribing according to %1RM can be misleading, because of increases in strength can occur since the last time it was measured, readiness (J. Weakley et al., 2021) , and there is also an extreme large variability in the number of repetitions performed at the same %1RM (Cooke et al., 2019b). Also RPE gauging can be affect by sleep, caffeine music and how close to failure is the set (Hackett et al., 2017a; Haddad et al., 2013, 2014, 2017).

Also, a possible strategy is by prescribing VBT speed metrics according to the ones intend to be stimulated in the F-V curve. Where if, previous individual F-V profile was taken, coaches and staff, could more accurately indicate the intended load, whereas practitioners might spend a bit more time in the “guess game” until they determine the correct intended load.

1.3.3.2 SPRINT TRAINING

VBT can also be applied during specific sprint training. By applying the method by Cross and colleagues (Cross, Brughelli, Samozino, Brown, & Morin, 2017) is possible to extrapolate which load will evoque the desired velocity loss/decrement (due to external load). This method might be superior compared to using a %BM, since the same %BM will probably induce different v.loss/decrement to different athletes (Cross et al., 2017), thus inducing different training stimulus.

1.3.3.3 READINESS, AUTO-REGULATION & LOAD ADJUSTEMENT

Many factors can contribute to players readiness either directly linked to external load imposed during training session and/or games (eg: fatigue) or their life outside of sports (eg: relationships) (Impellizzeri, Marcora, & Coutts, 2019b) and their recover capacity (Tavares, Smith, & Driller, 2017). By prescribing a target velocity range (eg: between 0,4-0,5 m/s for the squat) load will eventually be regulated according to the players readiness. Therefore, if the player is in a fatigued state, loads for that given exercise will be lower, but on the other hand, if the athletes is not in a fatigue state load will eventually go up in that training session.

1.3.4 VELOCITY LOSS

Velocity loss (V.Loss) is a metric related to VBT. It's the percentage of velocity that is lost compared either to the best or the first repetition during the set (Galiano et al., 2020; F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco et al., 2017; J. Weakley, McLaren, et al., 2020). It is important to notice that v.loss during a set of traditional resistance training has a different meaning that when applied during resisted sprints. Being the first related to fatigue accumulation during a set and the other to additional resistance, losing velocity compared to free sprint or overall fatigue comparing the velocity during the first or better sprint to worst.

1.3.4.1 INTRA-SET FATIGUE

V.loss is a metric related to VBT, which can measure the magnitude of perceptual, metabolic and neuromuscular response, thus fatigue (Sanchez-Medina & González-Suárez, 2009; J. Weakley, McLaren, et al., 2020) , imposed by a set according to the respective velocity loss attained, and the responses are reliable over long-term periods (J. Weakley, McLaren, et al., 2020). Lesser degree of velocity loss (10-20%) impose less neuromuscular fatigue (F. Pareja-Blanco et al., 2017; J. Weakley, McLaren, et al., 2020), while providing less short term decrements in jumping ability (J. Weakley, McLaren, et al., 2020) and higher performance for the long-term (F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco et al., 2017).

1.3.4.2 OVERALL FATIGUE

1.3.4.2.1 TRADITIONAL STRENGTH TRAINING

The acute fatigue cause by intra-set velocity loss will then carry-over to overall fatigue induced by the training session (J. Weakley, McLaren, et al., 2020). The higher v.loss thresholds are, the more impaired the neuromuscular will be at the end of training, on the other hand, the lower v.loss thresholds, lesser the impairment, thus less overall fatigue was accumulated. Regarding what is high and low v.loss thresholds, that might still be debatable, but when 30 and 40% v.loss where utilised compared to 10,15 and 20% (J. J. González-Badillo & Sánchez-Medina, 2010; F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco et al., 2017) it seems that up to 20% is probably safe in terms P.F, and therefore higher exertions and probably volume associated, which might lead to higher fatigue.

1.3.4.2.2 SPRINT TRAINING

Has sprint has only “one repetition” per set, that’s why is only included in the overall fatigue. In a study by Grazioli (Grazioli et al., 2020) where two groups performed resisted sprints (progressing weekly load (%BM)) from 45% to 65%, whereas one group stopped performing when they achieved either v.loss of 10% or 20% when compared to the best speed in in that session (first 2-4 sprints). The G10 although performed 33.75 (9.22) compared to G20, 48.78 sprints, the first group had considerably better outcomes in terms of sprint performance improvements. Another reason to believe that fatigue accumulation could potentially cause impairments, when adapting to a speed stimulus. Also it seems that a wider range of external load (20-80% BW), the previously tough, can be utilised for sled sprint with positive effects, although preferably v.loss (due to external load) should be preferred instead of %BW training (Lahti et al., 2020; J. B. Morin et al., 2017).

1.3.5 PRATICAL IMPLEMENTATION

1.3.5.1 VELOCITY TARGETS

According to the desired stimulus S&C coaches want to provide to the athletes, velocity targets can be prescribed according to the individual´s load-velocity profile for a given exercise. For example, figure 1 is an individual table for the squat exercise. This way practitioners can prescribe velocity targets according to the desired stimulus, for example, BB Back Squat 3x5 @0,50 m/s for training Strength, also having more precise idea to which load to start. If there is no individual L-V for that athlete, practitioners can use general velocity targets described in Mann (Mann, Ivey, & Sayers, 2015) to train those different qualities.

BB Squat

1RM Test	Load (kg)	Velocity (m/s)
	100	1,05
	140	0,77
	160	0,64
	180	0,5
	200	0,31
	208	0,21

Estimated RM	Minimum Velocity
220	0,19

	Strength		Strength-Speed		Speed-Strength		Speed	
%RM	100%	80%	80%	60%	60%	30%	30%	0%
MPV (m/s)	0,19	0,51	0,51	0,83	0,83	1,31	1,31	1,79
Load (kg)	220	176	176	132	132	66	66	0

Figure 1- Individual Load-Velocity Profile

1.3.5.2 VELOCITY LOSS TRESHOLDS

V.Loss thresholds can be implemented to control fatigue induced by the set, has mentioned above. This can be a useful tool to manage fatigue across the week or the entire season. Where preferably higher v.loss thresholds (20-40%) (J. Weakley et al., 2021) could be utilised during off-season, where a more general preparatory phase is allocated, since this thresholds tend to elicit improvements in conditioning, lean body mass and muscular endurance, but also associated with more fatigue (F. Pareja-Blanco et al., 2017; J. Weakley et al., 2021). In contrast, during the season, Lower v.loss thresholds (<20%) (J. Weakley et al., 2021) might be beneficial due to cause less fatigue, possibly causing less interference with performance outcomes (F. Pareja-Blanco et al., 2017; J. Weakley, McLaren, et al., 2020). V.loss thresholds can be used alongside velocity targets. For example 3x3-5 reps @0,50-0,45 m/s (10% v.loss)

Figure 2- High vs Low Velocity Loss: Response & Adaptation

1.3.5.3 VELOCITY SET CAP

The issue with using v.loss thresholds is that, manly if higher ones are utilized (20%-40%) is that due to fatigue accumulation across the sets, in which, the latter ones might lead to concentric failure (F. Pareja-Blanco et al., 2017; Sanchez-Medina & González-Suárez, 2009; J. Weakley et al., 2021), therefore Velocity Set cap can be utilized alongside velocity targets and v.loss metrics. Also, regarding resisted sprints, velocity set caps can be implemented, has in Grazioli study (Grazioli et al., 2020), that athletes stop sprinting when they reached 10 or 20% v.loss (due to fatigue). Since the group with 10% v.loss had greater improvements. Sprint sets could be caped when athletes reached 10% v.loss (X sprints x 20 meters velocity set cap 10%). Or for traditional strength training X sets x X reps 100kg @ set cap 0,36 & 10% v.loss.

1.4 CONCURRENT TRAINING

1.4.1 HYPERTROPHY

Muscle hypertrophy is the enlargement contractile elements and extracellular matrix (V. J et al., 2000). This increase in size, can be done by adding sarcomeres in parallel or in series (Schoenfeld, 2010a). In order to obtain muscle hypertrophy, a positive balance between muscle protein synthesis and degradation has to occur (Schoenfeld, 2010b). The pathway by which myofibrillar protein syntheses is stimulated is called mTOR, then promoting increases hypertrophy, strength, and power when resistance training is applied (Methenitis, 2018).

1.4.2 STRENGTH & POWER

Strength increases can be due to neural factors, hypertrophy and connective tissue (Methenitis, 2018). Power is the product of force (strength) and velocity (speed), therefore being dependent on structural (muscle size) the neural activation of the muscle (greater firing unit and/or activation and myosin heavy chain (fiber type) (Schumann & Rønnestad, 2019).

1.4.3 INTERFERENCE EFFECT

The inference effect during concurrent training (CT) only seems to affect muscle hypertrophy and strength related adaptations, but not the other way around (J. M. Wilson, Marin, et al., 2012a), at least up to a certain point (Doma, Deakin, & Bentley, 2017). Nevertheless, if resistance training (RT) is performed in non-organize and thoughtful way, might indirectly interfere with endurance due to fatigue (overtraining and overreaching), mitigating running performance for endurance runners, thus possibly its adaptations. Also, and contrary to the single mechanism (mTOR pathaway) that promotes muscle hypertrophy, the underpinning processes that support endurance adaptations result from a variety of metabolic signals and molecules (Methenitis, 2018).

1.4.3.1 LOW ENERGY LEVELS

One of the mechanism by which endurance can interfere with strength training is possible due to increase in AMP, that will trigger AMPK signalling, which, in turn will down-regulate muscle protein syntheses, by inhibiting mTOR (Methenitis, 2018; Nader, 2006; Schumann & Rønnestad, 2019). Also SIRT1 which is closely linked to AMPK signalling (Cantó et al., 2010) can possibly inhibit mTOR signalling (Ghosh et al., 2010). AMPK acts has monitor for energy availability in the cells and its activated with an increase in ADP/ATP ratio (lower energy levels), an during endurance exercise (Nader, 2006). Therefore is possibly to assume that, more training volume, which is already link to interference effect (J. M. Wilson, Marin, et al., 2012a), will demand more energy resources. Finally ER stress can also potentially effect MPS, and this can be triggered by periods also by high glycogen depletion and/or lipid exposure (Baar, 2014). An alternative explanation, could be the increase activity of p53 (Schumann & Rønnestad, 2019), which is activated by either low intensity/continuous or high intensity/ HIIT for equalized volume (Jonathan D. et al., 2012) further enhanced when the metabolic stress is increased by reduced carbohydrate availability (Bartlett et al., 2013).

1.4.3.2 FIBER-TYPE SHIFTING

It is know that resistance training induces, to a greater extent increases in faster twitch muscle fiber than compared to the slower one (Dudley & Djamil, 1985; Schumann & Rønnestad, 2019).On the other hand, endurance training can change muscle-fiber distribution, towards a more type I metabolic profile (Nader, 2006; Schumann & Rønnestad, 2019). Also in a study by Pareja-Blanco (F. Pareja-Blanco et al., 2017), the group that was exposed to more v. loss (40%, due to fatigue), experience a decrease in myosin heavy chain type IIX (MHC-IIX), and also led to a decrease in jumping performance, both contrary to the other group (v.loss 20%). This shift might one of the biggest reasons why power is probably more affected than strength and hypertrophy outcomes (Schumann & Rønnestad, 2019)

1.4.3.3 NEURAL

Regarding the interference effects in the neural component the is not much evidence. Besides the architectural interference (fiber shift) that affects power, and probably all of the faster velocities of de F-V curve, since there evidence (although just in rats) that reduced maximal shortening velocity in type II fibers (Luginbuhl, Dudley, & Staron, 1984). Also, besides Häkkinen study (Häkkinen et al., 2003a) that identified that endurance inhibited increases in rapid neural activation, no further studies were able to isolate the neural mechanism affected by CT training.

1.4.3.4 MUSCLE DAMAGE

Muscle damage associated with eccentric loading from running might also play a role regarding the interference effect, whereas in cycling that is manly concentric, does not affect in the same magnitude (J. M. Wilson, Marin, et al., 2012a).

1.5 CONTINIOUS RUNNING VS HIGH INTENSITY INTERVAL TRAINING (HIIT)

When it comes to field based sports such has soccer, where there might be tasks that need to be responded with high burst action such and sprints, jumps and changes of direction, or even a combination of them (ex: repeated sprints, linear sprint followed by a change of direction, etc) the utilization of continuous running might relatively less specific when compared to HIIT training (Baker & Level, 2011).

Has follows and above mentioned, the goal of every training program should be to maximize training adaptations, that being, for endurance, it is reported that for an optimal stimulus (central and peripheral adaptations) , athletes should spent a couple of minutes near or above VO2max (T@VO2max) (Baker & Level, 2011; Buchheit & Laursen, 2013a). Also, it seems that training with high-energy demands, thus, high-volume/distance continuous running (>20 minutes) at a moderate intensity (<85%) (Baar, 2014; J. M. Wilson, Marin, et al., 2012a) will contribute to the activation of the mechanisms mentioned in the “Interference Effect” topic, augmenting the concurrent training effect phenomenon.

On the other hand, low-volume/distance of short burst (4-10 minutes, following the recommendations of Dan Baker (Baker & Level, 2011)) of some form of HIIT (Methenitis, 2018), has lower energy demands when compared to continuous running for matched volumes (Gibala & McGee, 2008; Kirsten A. et al., 2008; Romeu B., Mitch J, Vincent J, Patrick S, & Andrew S, 2017), additionally increasing PGC-1 activation to a greater extent compared to continuous endurance running (Gibala & McGee, 2008; Kirsten A. et al., 2008; MacInnis et al., 2017) leading mitochondrial biogenesis (Lundby & Jacobs, 2016). For these reasons, it's possible that, for field sport athletes, such has soccer players, HIIT training seems to propose less interference mechanism than continuous running, while providing a more specific and effective stimulus, with less energy demands (Low Energy Levels topic), which can affect mTOR, and thus, hypertrophy and the subsequent structural impact that has on strength and power outcomes. Also, the fact that HIIT training normally expose athletes so intensities near VO2max, demanding the recruitment of large motor units (type II muscle fibers) (Altenburg, Degens, Van Mechelen, Sargeant, & De Haan, 2007; Gollnick, Piehl, & Saltin, 1974)can potentially mitigate some of the fiber shifting that happens in when low-to-moderate intensity/long distance training is performed and the more oxidative muscle fibers (type I) are stimulated but further studies should be carried.

HIIT training is a way to program endurance training at near or maximal running speeds/intensities. HIIT training can be categorized and divided according to the pre-defined formats, such has repeated sprint training (RST), sprints interval training (SIT), all out sprints (ie. Wingate) , and long or short repeat bouts with high but not maximal intensity exercise (Buchheit & Laursen, 2013b). Independent of which format is chosen, they will "tap" into the metabolic system at different levels (ATP and PCr, anaerobic glycolytic and oxidative metabolism) (Gastin, 2001) , with an inherent fatigue associated, imposed by the neuromuscular load and musculoskeletal strain (Buchheit & Laursen, 2013a).

For example, in a study by (Buchheit & Omeyer, 2002)where three types of HIIT training where imposed to 14 highly trained handball players. Which were two sets of either short HIIT 10s [110% Vift] /20 s [0], RSS 12 x 5 s [all out sprints]/25s [0] or short HIIT 30 s [93%Vift]/30 s [0]. Countermovement jump only increased after HIIT work in the 10s/20s but not in the other (RSS and short HIIT

30s/30s). Showing that intensity alone did not dictate muscular fatigue, but also the metabolic perturbations (metabolite accumulation) may be enough to cause neural and muscular alterations (Girard, Mendez-Villanueva, & Bishop, 2011).

Finally Buchheit (Buchheit & Laursen, 2013b) suggests that there is a sweet sport interval (figure 4) running intensity , where it might lead to improvements in endurance at high speed running, where to low of an intensity might not induced the desired adaptations, and to high might induced to high of a neuromuscular strain and acute decrements in performance.

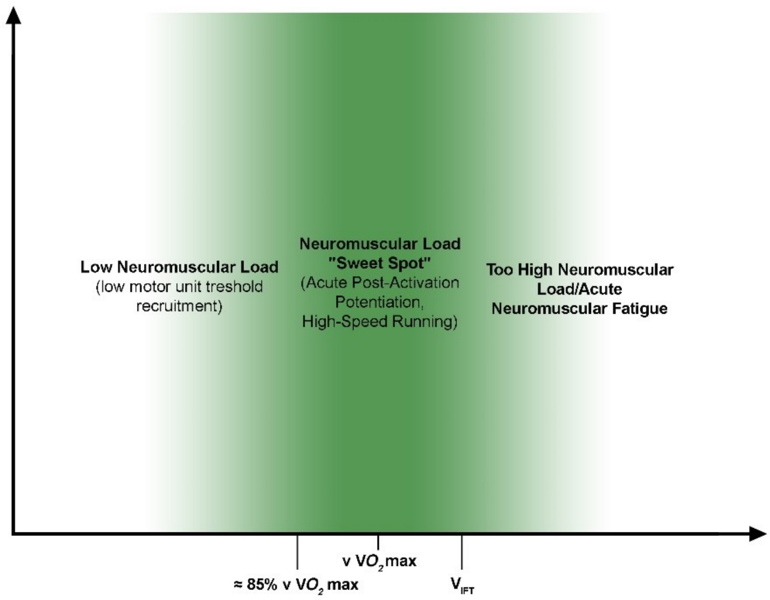

Figure 3- HIIT training "sweet spot"

CHAPTER 2- ORIGINAL ARTICLES

Paper 1

Methodological characteristics, physiological and physical effects, and future directions for combined training in soccer: A systematic review

Jorge Ribeiro, José Afonso, Miguel Camões, Hugo Sarmento, Mário Sá, Ricardo Lima, Filipe Manuel Clemente

Methodological characteristics, physiological and physical effects, and future directions for combined training in soccer: A systematic review

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Authorship Contributions: JR and FMC lead the project, ran the data search and methodological assessment, and wrote and revised the original manuscript. MC, MS and RL, revised the original manuscript. JA ran the data search and methodological assessment and wrote and revised the original manuscript. HS executed the methodological assessment, wrote and revised the original manuscript.

Abstract

Background: Combined training (CT) may combine strength and endurance training within a given time period, but it can also encompass additional protocols consisting of velocity, balance, or mobility as part of the same intervention protocol. These combined approaches have been becoming more common in soccer. **Objective:** This systematic review was conducted to (1) characterize the training protocols used in CT studies in soccer, (2) summarize the main physiological and physical effects of CT on soccer players, and (3) provide future directions for research. **Methods:** A systematic review of Cochrane Library, PubMed, Scopus, SPORTDiscus, and Web of Science databases was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The PICOS were defined as follows: (P) soccer players of any age or sex); I (CT combining strength and endurance or sprinting or balance or mobility training); C (the control group (whenever applicable), with or without comparative interventions in addition to usual soccer training); O (acute and/or chronic responses: biochemical, physiological and physical); S (must have at least two groups, either randomized or non-randomized). **Results:** The database search initially identified 79 titles. From those, eight articles were deemed eligible for the systematic review. Three studies analyzed acute responses to concurrent training, while the remaining five analyzed adaptations to CT. In those tested for acute responses, physiological (hormonal) and physical (strength and power external load, internal load) parameters were observed. Adaptations were mainly focused on physical parameters (strength and power, sprints, jumps, repeated sprint ability, aerobic, change-of-direction), with relatively little focus on physiological parameters (muscle architecture). **Conclusions:** Short-term responses to CT can affect hormonal responses of testosterone after resistance training with internal and external load. In turn, these responses' effects on strength and power have produced mixed results, as have adaptations. Specifically, strength and hypertrophy are affected to a lesser extent than speed/power movements. Nevertheless, it is preferable to perform CT before endurance exercises since it is a limiting factor for interference. Volume, intensity, rest between sessions, and athletes' fitness levels and nutrition dictate the degree of interference.

Keywords: soccer; athletic performance; strength training; high-intensity interval training; resistance training.

1. Introduction

Combined training (CT) combines different modalities of training, often involving both strength/resistance and endurance training to improve muscular strength, power, and aerobic capacity and power [1]. CT can be done within the same training session or during independent sessions [2]. However, other combinations consisting of strength and velocity, balance, or mobility can also be considered within a CT regimen. CT can be helpful in specific contexts, such as in intermittent sports that require more than one determinant physical quality to achieve favorable athletic performance [3].

Due to its high metabolic, physiological and physical demands [4,5], soccer is an example of a sport in which CT can be employed [6,7], considering that an optimal strength and endurance program is essential. The game of soccer consists of periods of low- to moderate-intensity, interspaced by high-intensity or all-out efforts [8]. The vast majority of a soccer match is spent performing low-intensity activities, which can represent almost 90% of all actions performed [9]. Despite the prevalence of low-intensity actions, high-intensity actions such as accelerations, sprints, jumps, duels, and kicks strongly influence a team's and player's performance, namely considering specific important moments (e.g., counter-attacks, transitions, goals) [10] that can change a game's outcome [11].

Considering that the high-intensity and determinant actions that occur in a match are strength and power-dependent, it is expectable that specific strength and power training protocols are part of the weekly training plan of the players [12]. Nevertheless, and considering the prevalence of low-to-vigorous running over 90 minutes, endurance training can also be achieved using different continuous and intermittent methods [13]. Other determinant qualities such as maximal velocity, agility, and balance might also be important to sustaining the demands of the game [14,15].

Since endurance training seems insufficient to guarantee that an appropriate stimulus for improving neuromuscular capacity is introduced, resistance training (RT) has been highly recommended to complement the field-based training sessions (which are usually focused on endurance stimuli and tactical/technical development) [16,17]. A well-developed strength capacity can help soccer players sustain other capacities, considering the relationships between strength and jumping or sprinting performance [16]. Additionally, strength training may help soccer players improve their running economy [18], which is important for mitigating the effects of fatigue, supporting the ability to repeat high-intensity efforts [19], and improving change-of-direction actions [3].

However, the impact of CT is not limited to the potential physiological or physical adaptations (or the chronic effects derived from a specific period in which a stimulus is provided). CT also produces a given acute or transitory effect in which the stimulus temporarily changes physiological or physical dimensions. While some reviews have addressed the effects of CT in performance outcomes and physiological changes [20,21] in different sports [22–24], a characterization of training protocols in soccer is lacking. For instance, it was found in non-soccer athletes that power is the most important variable that can be affected by CT [20]**.** Additionally, it was found that high volume, moderate, continuous and frequent endurance training negatively affect the resistance training-induced adaptations, probably by inhibition of the Protein kinase B—mammalian target of rapamycin pathway activation, of the adenosine monophosphate-activated protein kinase but in opposition, it was found that short bouts of high-intensity interval training or sprint interval training could minimize the negative effects of concurrent training [21].

Since factors such as training intensity, frequency, and volume can strongly influence training adaptations, it is vital to understand how CT is implemented in soccer.

For the above-mentioned reasons, there is a need for a systematic review. Such a review could help to characterize experimental CT protocols in soccer players and provide a general overview of the physiological and physical effects on the players. A scoping review may help coaches to achieve an overview of the possibilities for applying CT in soccer. This kind of review could also help researchers define future projects and intervention directions. Therefore, the aim of the present scoping review was threefold: (1) to characterize the main elements of CT studies (e.g., training protocols) conducted in soccer, (2) to summarize the main physiological and physical effects of CT on soccer players, and (3) to provide directions for future research.

2. Methods

This systematic followed the Cochrane Collaboration guidelines (Green & Higgins, 2005). The scoping review strategy was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines (Moher, Liberati, Tetzlaff, & Altman, 2009). The P.I.C.O.S. (Population or problem; Intervention or exposure; Comparison; Outcome; Study design) is: P (soccer players of any age or sex); I (CT combining strength and endurance or sprinting or balance or mobility training); C (if applicable, control group, with or without comparative interventions in addition to usual soccer training); O (acute and/or chronic responses: biochemical, physiological and physical); S (must have at least two groups - randomized or non-randomized). The protocol was published in INPLASY (International Platform of Registered Systematic Review and Meta-analysis Protocols) with the identification number of INPLASY2020110132 and DOI 10.37766/inplasy2020.11.0132.

2.1.Eligibility criteria

The inclusion and exclusion criteria based on PICOS can be found in table 1.

< TABLE 1

The screening of the title, abstract and reference list of each study to locate potentially relevant studies was independently performed by the two authors (FMC and JA). Additionally, they reviewed the full version of the included papers in detail to identify articles that met the selection criteria. An additional search within the reference lists of the included records was conducted to retrieve additional relevant studies. A discussion was made in the cases of discrepancies regarding the selection process with a third author (J.R.). Possible errata for the included articles were considered.

2.2.Information sources and search

Electronic databases (Cochrane Library, PubMed, Scopus, SPORTDiscus and Web of Science) were searched for relevant publications prior to December 3, 2020. Keywords and synonyms were entered in various combinations in title and/or abstract for the following terms: ("Soccer" OR "Football") AND ("concurrent training" OR "combined training" OR "cross training"). Additionally, the reference lists of the studies retrieved were manually searched to identify potentially eligible studies not captured by the electronic searches. Finally, an external expert has been contacted in order to verify the final list of references included in this scoping review in order to understand if there was any study that was not detected through our research.

2.3.Data Extraction

A data extraction was prepared in Microsoft Excel sheet (Microsoft Corporation, Readmon, WA, USA) in accordance with the Cochrane Consumers and Communication Review Group's data extraction template (Group, 2016). The Excel sheet was used to assess inclusion requirements and subsequently tested for all selected studies. The process was independently conducted by the two authors (FMC and JA). Any disagreement regarding study eligibility was resolved in a discussion. Full text articles excluded, with reasons, were recorded. All the records were stored in the sheet.

2.4.Data items

The main outcomes defined for data extraction were: (i) acute or immediate effects related to CT exposure (internal load, external load, hormonal responses and strength and power); and (ii) adaptations related to CT interventions (pre-post differences in strength and power, muscle architecture, aerobic performance, sprinting, jumping, change-of-direction [COD] and repeated sprint ability [RSA]). The acute or immediate effects are related to immediate and transitory effects of CT in internal load (e.g., psychophysiological responses (Impellizzeri, Marcora, & Coutts, 2019a), e.g., heart rate, rate of perceived exertion [RPE], blood lactate), external load (e.g., physical demands related to the exercise (Impellizzeri et al., 2019a), e.g., distances covered at different speed thresholds, accelerations, decelerations), hormonal responses (e.g., testosterone, growth hormone) and strength and power (e.g., vertical jump height using tests as squat, countermovement or drop jumps). The adaptations represent a structural change in fitness status in which the following measures were extracted: (i) strength and power (e.g., repetition maximum); (ii) muscle architecture (e.g., changes in fascicle angle, muscle thickness); (iii) aerobic performance (e.g., maximal oxygen uptake, distance in field-based tests); (iv) sprinting (e.g., time in specific distances, as 10-, 20-, 30-meters); (v) jumping (e.g., vertical jump in testes as squat, countermovement or drop jump; horizontal jumps); (vi) COD (e.g., time in tests as 5-0-5, pro-agility, T-test); and (vii) RSA (e.g., time or fatigue index in tests of repeated-sprints in different distances).

Additionally, to the main outcomes, the following information was extracted: (i) type of study design, number of participants (n), age-group (youth, adults or both), sex (men, women or both), competitive level (if available), and type of original articles included (study design).

2.5.Assessment of methodological quality

The version 2 of the Cochrane risk-of-bias tool for randomized trials (RoB2) (J. A. C. Sterne et al., 2019) was used to assess the risk of bias in the included randomized-controlled trials. Five dimensions are inspected in this assessment tool: (i) bias arising from the randomization process; (ii) bias due to deviations from intended interventions; (iii) bias due to missing outcome data; (iv) bias in measurement of the outcome; and (v) bias in selection of the reported result. Using RoB2 a qualitative synthesis was performed. Two of the authors (JA and HS) independently assessed the risk of bias. Any disagreement in the rating was resolved through discussion and by a third author (FMC).

The Cochrane risk of bias in non-randomized studies of interventions (ROBINS-I) was used to assess the risk of bias in included non-randomized intervention studies (J. A. Sterne et al., 2016). Three domains are analyzed in this assessment tool: (i) pre-intervention (bias due to confounding; bias in selection of participants into the study); (ii) at intervention (bias in classification of interventions); and (iii) post-intervention (bias due to deviations from intended interventions; bias due to missing data; bias in measurement of outcomes; bias in selection of the reported results). Two of the authors (JA and HS) independently assessed the risk of bias. Any disagreement in the rating was resolved through discussion and by a third author (FMC).

3. Results

3.1. Study identification and selection

The searching of databases identified a total of 79 titles. These studies were then exported to reference manager software (EndNote™ X9, Clarivate Analytics, Philadelphia, PA, USA). The screening process and the flow until the included articles can be observed in Figure 1.

< FIGURE 1

3.2. Study characteristics and training protocols

Eight studies were included in this review [6,7,31–36], three of which [6,31,32] looked at acute responses and five of which [7,33–36] considered chronic adaptations. Three of the studies on chronic adaptations involved teenagers [7,33,34], and one involved young adults [36]. Meanwhile, of the studies of acute responses, two focused on young adults [6,31], one focused on teenagers [32], and one focused on children [35]. Athletes' fitness levels varied from healthy male volunteers (control group) in Kotzamanidis's study [7] to lower-level athletes [7,34] moderate-level (or semi-professional) athletes [31], and high-level (or professional) athletes [6,32,33,35,36]. The characteristics of the included studies can be found in Table 2.

<TABLE 2

CT training was applied in all the studies [6,7,31–36]. Strength and endurance (either soccer-specific endurance, HIT, or a combination of both) were combined in [6,33–36], with interventions lasting between five [33,36] and 12 weeks [35], with [34] lasting six weeks and [6] lasting10 weeks. Other studies had different training modalities, such as a combination of speed and plyometrics [34] or strength and speed [7] lasting six and 13 weeks, respectively. The two other studies [31,32] also combined strength and endurance, but subjects were submitted to just two training interventions with 72 hours of rest between them. The details of the interventions and training protocols can be found in Table 3.

<TABLE 3

A conceptual overview elaborated by the authors of this scoping review can be seen in Figure 2. This overview aims to systematize the complexity of the field and presenting it in an intelligible manner.

< FIGURE 2

3.3.Methodological quality

The randomized studies were assessed using RoB 2 instrument (table 4). The assessment can be observed in table 4. The two included studies presented an overall score of some concerns. The dimensions of randomization process, measurement of the outcome and selection of the reported result were classified with some concerns.

<TABLE 4

The non-randomized studies were assessed using the ROBINS-I (table 5). The studies of (Enright et al., 2015) and (Enright, Morton, Iga, & Drust, 2017b) were classified with critical risk in the dimension of reaching risk of bias judgements for bias due to missing data, while the study of (Enright et al., 2017b) was also classified with critical risk in the dimension of reaching risk of bias judgments for bias in selection of the reported result. From the six included non-randomized studies, four had an overall classification of moderate/serious risk, while two had critical risk.

<TABLE 5

3.4.Results of individual studies: acute (immediate) effects

The synthesis of the results regarding the acute effects of concurrent training on the acute effects (i.e., hormonal responses, strength and power, and internal and external loads) can be found in Table 6.

Two of the included studies [31,32] tested athletes' hormonal responses in regard to CT modality order. Both studies reported no main effects of testosterone (T) or cortisol (C) between conditions. In another study [32], the researchers observed changes in T and C and typical to the one observed in the diurnal fluctuations in the absence of exercise; no significant changes were observed between trails. Only human growth hormone (hGH) had different responses between trails, having an increase in one trail but decreasing in the other. As mentioned by the authors, this could be because the trail in which hGH had decreased also had a shorter rest period between bouts (60 min vs. 105 min). The dietary strategy employed was also different regarding the absence of carbs, while also contributed to this result.

Other researchers [31] reported the same finding regarding differences between groups, with the exception of T right after the training bout of RT. T had a moderate and significant effect between CT trails, favoring RT, followed by endurance, which was also speculated by [32] (though this expected finding did not present itself). Also, since [32] was carried out at 17:30 or 20:30, RT training could have disrupted the normal circadian rhythm, which could have led to the potentiation of the following training session [37].

In [31], jump height (JH) and relative peak power output (PPO) were measured. Athletes' performance in both measures decreased. JH decreased by -2.2 (3.1) in the SSG+RES condition and by -4.1 (2.6) with no significant difference between protocols (p=0.052). PPO followed the same trend (JH, SSG+RES -0,84 (2,75) vs. RES+SSG -3,53 (2,48)), with no significant differences between protocols (p= 0.009). Both measures were taken immediately after the first training bout.

Concerning specific performance measurements/external load during soccer-specific training, only two studies [6] [31] employed tests with opposing results. In [6], a significant difference in total distance covered was observed between groups (ET+RT 6213 (958) vs. RT+ET 5942 (1057)). Additionally, HRmax (min) favored the ET+RT 11(2) group (vs. RT+ET 5 (12)), suggesting that players ran more often and at a higher intensity when ET was performed first.

On the other hand, [31] found no significant differences between groups when considering total distance, HSR distance, and *PlayerLoadTM* when dietary intake was controlled and equated for both groups. Although HRmax (min) and HSR distance (m) are not the same, both have been used to measure "quantity" and indicate training intensity [38].

The same studies mentioned above considered internal load. Contrary to external load, both studies found no significant differences between groups. It is unknown whether this is a consequence of the significantly lower external load as mentioned above. Nevertheless, when ET was performed first, and when more running was performed at a higher intensity, players still went through an RT program with 4RM-12RM, and this near-failure task did not affect either RPE measurement.

Also, it is interesting that the avg. sRPE and RPE have maximum scores of 7 and 6 maximum, respectively, that for a near failure task for a couple of sets, out of the ordinary, but ending up with an insignificant difference in avg. sRPE and RPE between training order. The same happened in [31], where the RPE score was higher (see Table 4), although no difference was found when the training order was switched.

< TABLE 6

3.5.Results of individual studies: chronic (adaptations) effects

The synthesis of the results regarding the effects of concurrent training on fitness dimensions (strength and power, muscle architecture, aerobics, sprinting, jumping, change-of-direction, and repeated sprint ability) can be found in Table 7.

Only one study [33] reported changes in muscle architecture. Although neither group exhibited significant differences pre- to post-test or between groups regarding muscle thickness, the S+E had a 1% increase at the distal location, while E+S had an 8.8% increase. This seems contradictory at first since, in theory, the players in this group would perform S in a more fatigued state, possibly limiting their training volume, which is linked to muscle hypertrophy [39] ($S + E$; 13443 ± 2485; $E + S$; 12341 ± 1574). Interestingly, and contrary to [40] and has mentioned above, this was not the case, leading to another possible explanation.

Also, significant increases (p=0.02) in pennation angle were found in both groups, again favoring the E+S group (S+E 7.9% vs. E+S 14.3 %), with a large effect for the E+S group. It is unclear whether this difference in pennation angle was due to training order or nutrition (or both), as there are many confounding factors. Nevertheless, we can speculate that training order, in addition to nutrition, impacts how muscles adapt.

Four of the studies included in this review address strength and/or power measurements [7,33,35,36]. Lower body strength was measured by 1RM back squat (1RM BS) in all four studies, with mixed results. For example, [36] reported similar improvements in 1RM BS (HIT-STR 19.7% vs. STR-HIT 19.1%), whereas [33] did not (E+S 19.1% vs. S+E 10.3%). Also, in [35], no significant differences were reported between the SE and ES groups' changes in 1RM BS and Bench. Interestingly, the ASE group had fewer gains in 1RM BS than the SE group but not the ES; conversely, the ASE group had fewer gains in 1RM Bench than the ES group but not the SE group.

Multiple factors affect strength [41], more specifically, in dynamic exercises, such as the back squat compared to isometric ones due to technical factors. Regarding power development, [33] presented no significant differences in changes regarding IMVC-LR (E+S 27% vs. S+E 20%) though larger effects were imposed on the E+S group. Also, [35] found no significant differences in changes between groups regarding med ball toss performance. The findings in [33] regarding IMVC-LR could be explained by a combination of reasons similar to those presented for muscle thickness and pennation angle.

When it comes to upper body strength and power, the results showed no differences in training order, except for the ASE group. However, considering that athletes' age and PHV were not determined, there might be just a question about maturation within the group or other factors since the SE and ES groups were similar. Thus, if there was a case for better adaptation, it would probably alternate between RT and endurance. Moreover, power did not differ in this study when comparing med ball toss scores.

Two studies included in this article [35,36] measured outcomes related to aerobic metrics. Both studies employed the Yo-Yo Intermittent Recovery Test (YYIRT), either at level 1 or 2. In both studies, athletes were able to achieve significant improvements in YYIRT distance pre- to post-test. Furthermore, no significant differences in changes between groups were found in either study. In [35], improvements in the YYIRT1 between 79% and 54.4% were found for the intervention groups. Also interesting was the fact that the control group of this study exhibited a 42% improvement in the same test.

Of all the studies included, four [7,33,35,36] tested for some type of jumping ability. A clear trend emerged in all the studies that included a squat jump (SJ) and a countermovement jump (CMJ) (i.e., the intervention groups), independent of training order, for participants who were not exposed to any type of high-intensity plyometric activity (including speed work). These participants did not experience any significant pre- to post-intervention increases in CMJ (see Table 5). Even when RFD (IMVC-LR) increased, such as in [33], it was able to increase SJ. There are a few possible reasons for this. For one, all athletes in the studies where no type of high-intensity plyometric activity was employed were considerably strong at baseline (1RM BS or IMVC-PF measures); therefore, strength was not a limiting factor in jumping performance for these athletes.

Sprinting tends to follow the same ideology as jumping, with the exception of [33], where the intervention group only had traditional resistance training [7] (STR group), which seemed to be an insufficient stimulus, or the correct type of one in order to increase sprint ability, in either 10-m or 30-m. It seems that athletes can improve sprint performance through strength training [42], but only to a certain point [43,44]. The changes in sprint performance observed by Enrigth [33] could be due to changes in pennation angle [45].

Three of the studies [34–36] evaluated agility or change-of-direction. All interventions improved change-of-direction ability pre- to post-training. No differences were found between groups, with the exception of the SE group in the study of Makhlouf [35]. In this study, ES improved by around 4.2% for both cases. Alternated strength and endurance (ASE) improved by about 5.6%, while the SE group improved by only 1.6%, indicating a significant difference in changes between groups.

This difference between the SE and ES groups is interesting since children have a more generalized response to training stimulus than adults [35]. However, the SE group only improved by 1.6% in a 12-week study, which is close to what was observed in [36] (HIT-STR 1,1% (1.5) vs. STR-HIT 0.9% (1.5)). However, [8] included adults and lasted just five weeks after de-training. A possible explanation for this could be that [35] did not include any tests for participants' maturation status, which could have affected their baseline performance metrics and their responses to the training stimuli [46,47]. On the other hand, none of the other tests that account for strength, power, and speed showed any significant differences pre- or post-intervention when comparing the ES and SE groups. Thus, there is no clear explanation for these results.

Another interesting fact was that in [34], interventions did not use resistance training— only plyometric and speed training (linear sprints and COD drills) were performed—but still achieved similar results (CDG 4.2% vs. CWG 5.0%) as in [35] with an older population (~17 years). These results could be explained by the fact that plyometric training can increase an athlete's ability to utilize the stretch-shortening cycle [48], which might impact COD ability [49].

Two studies [35,36] reported changes in RSA performance1 with no significant differences in changes between groups. Both studies showed similar results regarding improved RSA ability using two different training strategies, which probably caused some differences in training adaptations that contribute to RSA performance.

In the intervention in [34], the mechanisms which most likely enhanced RSA ability were increased running economy due to plyometric work [50], which reduces the amount of energy used per set and, consequently, leaves the athlete with more energy availed for the next one. The other mechanism that improved RSA was the increase in the 30-m sprints due to sprint work (not negating the fact that plyometrics also contribute to sprint performance).

In [51], the most robust predictor of RSA was anaerobic power, which is, for example, the fastest individual's sprint time. So, the combination of these factors led to an increased RSA for [34]. On the other hand, [36] employed a combination of strength and power training, resistance training, and plyometrics while also employing HIT training. Although the 10-m sprint time improved, this did not necessarily translate to an improvement in 30-m sprint time due to differences in kinetics and kinematics. The degree to which this might influence RSA is probably less than in [34].

< TABLE 7

4. Discussion

This systematic review presents the main effects of concurrent training normally used in a soccer context, either in acute responses or chronic adaptations. It was also investigated whether the order of the training modality affects any responses to the stimulus.

4.1. Discussion of evidence: Acute effects

4.1.1. Hormonal responses

Two studies [31,32] found no significant changes in either testosterone (T) or cortisol (C), with the exception of T right after RT training in [31]. Short-term changes in T can enhance the performance capacity of the neuromuscular system, such as second messenger and lipid/protein pathways, behavior and cognition, motor system, energy metabolism, and muscle properties [52]. This in combination with post-activation potentiation (PAP) [53], which is the enhancement of muscle force and muscle rate force development (RFD) [44,45] using high-loads [56]. For example, in RT, increased performance may be observed [37] in the following training bout, as mentioned above.

Overall, T and C did not have any main differences between studies and trials, with the exception of [31], right after the strength training (although the same was also expected in [32]). The ability of T to disrupt the normal circadian rhythm may have potential use in a normal training scenario to potentiate specific soccer training for teams who have late-night training sessions or even when travelling for those who are suffering from jet lag. This is possible because T can enhance neuromuscular force-generating properties [52] and training motivation [57].

To the best of the authors' knowledge, there are no guidelines for what minimum dosage of RT can be used to increase T without imposing excessive fatigue. In [37], players completed three sets of 3RM for bench press and squat. Although the volume was low, the intensity was high in close proximity to failure, and players were able to recover and still get the benefit of increased T and possibly PAP. Also, players were trained and strong (lifting approximately 1.5 × BW and almost 2 × BW in bench and squat for three reps), and their baseline strength might have an influence on the prediction of free-ton training performance [58]. Their training experience might also have a role in the training intensity and volume needed to raise T and still recover in time for the following session. Finally, it would be interesting if an upper body session only could affect T release and still potentiate the lower body performance by PAP and T release or even both.

4.1.2. Strength and Power

Regarding [31], both groups decreased their jumping ability and power-related characteristics. These changes could be explained by the near proximity to failure of the RT exercises, and one principle of PAP is that the exercises imposed should not cause fatigue [56], which has possibly not the case since the close proximity to failure. Additionally, this could also be explained as task-dependency fatigue [31]. Nevertheless, there were no significant differences between groups immediately after or 24 hours after the first training bout.

If the RT training was not as hard, near failure as it was or the time between the end of the RT training and testing was longer, perhaps the observed decreases would be lowered or potentiated. Therefore, it is plausible that volume and intensity at which loading is imposed plays a bigger role when there is less time between sessions regarding the impact on the performance of athletes following a training session.

4.1.3. External Load

Two studies [6,31] found contradicting results in terms of external load measurements. However, the ET+ RT group had consumed a total of 1.25 g/kg of carbohydrates after finishing RT training, by which 0.45 g/kg before the first bout (ET). This was contrary to the RT+ET group, who consumed the 0.45 g/kg of carbohydrates before ET but had already completed the RT. The observed difference affects running performance [59], probably HRmax to a higher degree due to its dependency on carbohydrates [40, 41]. Meanwhile, in [31], dietary intake was controlled in both trials, and players received the same amount of carbohydrates in between training bouts, which could have led to the differences in the results. Also, it is unknown whether the pitch size and/or exercise demands were adjusted because players engaged in a previous RT training. Finally, 17 CT sessions were performed during the 10-week study, 11 of which were performed in weeks 1-3, representing 65.6% of total volume performed (weeks 1-3 had a significantly higher total volume than weeks 4-10 ($p=0.04$)), possibly indicating that total volume my play a role when accounting for interference with the soccer-specific performance in training.

When food intake was equalized between trails, no significant differences were shown, not only for high-intensity efforts but also for total distance covered. Furthermore, PlayerLoad, although not included in [6], can also indicate intensity by including acceleration and decelerations. From an RT perspective, both studies are not that different. In [6], players lifted between 4RM and 12RM. Unfortunately, it is not described whether these were the true RMs taken to failure. Nevertheless, in [31], volumes were extremely high in the first weeks (1-3), which is a proxy for fatigue, although the volume was possibly lower due to the RT program repetition scheme (4×4). At least in the squat, sets were taken to near failure, which is another proxy for fatigue. Rest time between bouts was also probably not a very significant differentiator [31] 120’ vs. [6] 75 (48).

To summarize, although both studies have different outcomes, the volumes implemented in [6] in weeks 1-3 might have influenced the external load in the two trials. Therefore, it would be interesting to know the pitch sizes and details of the exercises—

specifically, whether they were less intense on the days that RT training was employed before ET, as this would have changed the external load outcomes. In [31], no differences were shown for external load or jumping ability, although jump height might fully explain fatigue [62] if it really was to a big extended, probably significant differences could be seen.

4.1.4. Internal Load

Two studies [6,31] measured the impact of the training order of CT training, with differing results. Internal load is the way the body responds to the external load imposed on athletes. The external load in [6] was extremely high in the first three weeks compared to [31]. This could have impacted internal load indicators such as RPE, creating a significant difference in one study [6] but not the other [31]. Also, RPE scores do not follow up with the training employed at least in RT, or soccer-specific training was too light to equate to those average RPE or players were not sufficiently familiarized with the process, bringing the validity of the data into question. Finally, one study only took two interventions [31], while the other involved 17 [31], which leaves more room for other confounding factors (e.g., weather and other psychophysiological factors) to affect the perception of effort/internal load, influencing the athletes' responses to the stimulus [28] to a greater degree for Enright [6] than Sparkes [31]. Future research using RPE with GPS data based on RSImod or RSI data instead of jump height alone use would be interesting.

4.2. Discussion of evidence: Adaptations

4.2.1. Muscle Architecture

In [33], no significant intra- or inter-group pre- to post-intervention differences were found, but there was a difference regarding muscle pennation angle.

As seen in subsection 4.1.3, nutrition also has an important role, and the E+S group consumed more key nutrients (carbs and protein) [6] between training bouts. More specifically, the S+E group only consumed protein between workouts. It is known that together with AMPK and SIRT1, ER stress leads to mTORC1 inhibition. This could be caused by high lipid exposure and glycose deprivation [24]. In this way, the S+E group could have been exposed to a less positive muscle protein balance, therefore blunting the potential for muscle hypertrophy.

One study [63] suggests that when performing concurrent training on the same day, the order and recovery time between strength and endurance can influence acute signaling responses. Thus, in the S+E group, the anabolic signaling mTOR could be later blocked by the signaling cause endurance training via the AMPK/SIRT-1 pathway, thereby limiting this cascade of events that promote strength-related adaptations, including adaptations in pennation angle.

In summary, nutrition has a key role in supporting muscle adaptations caused by training stimuli. When it comes to increasing muscle thickness, it is recommended that athletes consume carbohydrates before a workout and protein afterward to maximize muscle hypertrophy [64]. Also, if training endurance is implemented after resistance training, athletes are recommended to consume carbohydrates to prevent muscle loss catabolism [64].

If possible, although it is not a reality for all teams, the ideal scenario would be to separate endurance from resistance training by six hours to maximize gains in muscle hypertrophy [21]. When this is not possible, possibly the best alternative would be to perform strength training after endurance training because endurance is a limiting factor for strength but not the other way around [65].

4.2.2. Strength and Power

Mixed results appear when comparing the results of the studies that addressed strength and power. Muscle hypertrophy affects strength outcomes [66]. In [33], as seen above, E+S had more muscle hypertrophy, which could be the cause for the difference in 1RM BS. In the same study, IMVC-PF had no significant difference changes between groups or pre- to post-intervention. Thus, the increases in 1RM BS were also probably due to improvements in technical proficiency in the movement rather than neural adaptations to a large degree, probably due to their training program repetition scheme, which is more for muscular adaptations than a neuromuscular, and because they were already strong athletes considering their bodyweight to force expressed in the squat and IMVC-PF. Therefore, the margin for progression is low.

Overall, based on the studies in this review, it looks like there is no significant difference in training order regarding strength and endurance, with the exception of [33] in the 1RM BS but not in the isometric test, with no technical factor associated with the exercise. These differences could be due to other factors (mentioned in the previous chapter) that have an impact on muscle hypertrophy and not much of an effect of neural adaptations regarding strength outcomes. According to [20], strength and hypertrophy are not as susceptible as power development to decreases during concurrent training.

It is well-established that fiber type affects muscle contractile velocity [67]. It is also possible to increase fast-twitch muscle fibers with strength and concurrent training, as shown in [65], as the strength alone group had a bigger shift in fast-twitch compared to the concurrent group. Thus, if the overall muscle thickness was greater in the E+S group, to a certain degree, it can be speculated that the shift or hypertrophy or a combination of both, regarding fast-twitch muscle fibers was greater causing, this with a greater pennation angle which is associated with muscular strength [33] caused a bigger slope in the IMVC-LR for the E+S group.

It is known that the upper body is not affected to the same degree as the lower body when it comes to concurrent training, especially in soccer, where the lower body is utilized the most during training [68].

It would be interesting to investigate a situation where training protocols are similar in terms of timing of the interventions and nutritional intake. Although it is invasive and expensive, analyzing fiber type shifts and hypertrophy would help to explain some training outcomes and guide the order training modalities.

It looks like when athletes are strong enough, increases in kg to a specific movement can be due to technical proficiency to a larger degree than neuromuscular adaptations, which is the end goal. So, if possible, a combination of isometric type testing and a dynamic exercise could be employed to understand if the stimulus imposed by the dynamic exercise is really provoking the desired adaptations (neural activation).

Finally, when it comes to concurrent speed and strength, strength gains do not seem to be affected as it shows in [7], probably because speed training is non-fating training that is generally performed with low volumes and total rest between sets. Therefore, the mechanisms by which endurance affects strength are not present in speed training.

4.2.3. Aerobic

The training interventions in both studies (Makhlouf et al., 2016; McGawley & Andersson, 2013) were effective for creating positive adaptions in aerobic power and capacity. This finding is in line with the findings of (Impellizzeri et al., 2006) that showed that SSGs are able to improve cardiovascular performance in adult soccer players. However, because the group in this study were young athletes, their potential to improve is even bigger, possibly enhancing the effects of training intervention. In fact, improvements in (McGawley & Andersson, 2013) were much lower (avg. 19.4 (23.4) than in the previous study, and the fact that this study started at the beginning of the pre-season could mean that players were de-trained and more likely to improve. Also, the duration of (Makhlouf et al., 2016) was 12 weeks vs. five weeks for (McGawley & Andersson, 2013), allowing less time for players to improve even further. It would also be interesting if (Makhlouf et al., 2016) had tested for athletes' maturation state since this can affect performance in various ways and directly or indirectly affect running performance when comparing results from pre-puberty athletes to post-puberty athletes.

Finally, independent of the study, players improved when they supplemented their regular soccer training with high-intensity endurance training and strength training on the same day. Also, the modality order did not seem to affect training outcomes, with the exception that alternating days between endurance and strength instead of doing it all in the same session does not seem to have any additional benefit.

4.2.4. Jumping

Studies [7,33,35,36] reported a combination of results varying from no improvements in various forms of jumping (SJ and CMJ) to improvements in only one

(SJ) or both. In fact, studies have shown that among well-trained athletes, strength training did not increase vertical jump performance [70,71]. Another reason might be the lack of exposure to a stretch-shortening cycle such as sprinting or jumping had in the [7,36], where athletes were exposed to sprints, which is a plyometric activity. CMJ increased only in the SE and ASE groups, perhaps due to fatigue, as workouts were separated by only 15 minutes, and endurance in the ES group could have limited the participants' neuromuscular abilities. Also, maturation might yet again also be a factor for adaptions in young athletes, such as in the previous study. These factors, either isolated or combined, were observed in [33,35], where only strength and endurance was employed, in [7], where STR and Con groups did not exhibit improvements in CMJ, and in [36] study, where the strength training included plyometric activities and power exercises. The only study where significant differences regarding training order were found was [35], which is contradictory since children have more generalized responses to training than adults and recover more quickly [72,73].

Due to different endurance training intensities and volumes of rest time between sessions, the results differed. However, it is plausible that there is a preference for plyometric activities to be performed before endurance so that there is no neural or peripheric fatigue during this type of training. Also, the choice of whether to perform strength or speed exercises before or after plyometric activity depends on the dose, as strength can serve as PAP (if not taken to failure), or it can increase fatigue (if done in proximity to failure or high volumes), or it can do a combination of both.

4.2.5. Sprinting

In general, the included studies have shown that it is possible to improve sprint performance with CT training, but probably with a caveat. Studies [43,44] show that strength training alone is not able to increase sprint performance in high-level athletes. Strength levels are probably not the limiting factor in sprint performance, such as the ones in [7,33], as measured by the ratio of 1RM BS and IMVC-PF to bodyweight. The difference in the study by Enrigth [33] is that athletes showed improvements in pennation angle that could have influenced their sprint performance [45]. Also, when pairing endurance with strength training, a slightly more positive tendency for the STR-HIT group to increase 10-m sprint performance [8]. This seems logical since strength training in this study comprised Olympic movements, plyometrics, traditional RT, and other types of athletic movements that were performed with no or less fatigue compared to their counterparts (HIT-STR), thus enhancing the capacity to express higher levels of force at higher speeds and having a small but increased transference for the 10-m sprint than the other group (HIT-STR).

Contradictory findings were presented in [35] compared to what is described in the literature, first because kids have more generalized adaptations and, second, because the differences in changes between groups were significant, which should not be attributed to training organization but to other factors such as maturation. Also, overall, the ASE group was the one with the fewest improvements, which also goes against [21], stating the more dispersed the training stimuli, the less likely it is that interference will occur and that and overall fatigue will increase from one training bout to another, potentiating the strength work by potentiating the expression of force during slow and fast velocity movements included in their training program.

When it comes to combining plyometrics and speed training, such as in [34], there is a slight tendency for better improvements when both modalities are performed on the same day. This could be due to the PAP effect, and the same criteria should be applied as in jumping topics.

The biggest improvement in the 30-m sprint was observed in [34]. This study also presented the fastest baseline 30-m time, leaving less room for improvement. It was also the study that combined plyometrics and speed training. This could reinforce the idea that the more specialized the athlete is and the greater their overall level and training experience, the more specific training has to be done to improve the desired physical quality or ability. Also, in the control group in [7], no changes were observed in sprint performance, which is in line with the literature, which states that specific soccer training is enough to maintain sprint performance but that to increase it, supplemental work should be employed.

Finally, when implementing strength training using only RT exercises that focus on the development of maximum strength without exploring other parts of the strength curve (whether from Olympics lifts, plyometrics, specific speed training, or a combination of all these), improvements in sprints can be marginal depending on the athlete’s fitness level.

4.2.6. Change-of-Direction

In general, athletes were able to improve their COD ability with no differences observed between groups. Plyometric training and speed training can improve the rate of force development and overall power characteristics [74] that can have an impact on COD ability [49,74]. This, together with the more specific training, practicing the COD itself, as has been done in this study, can have a big impact on COD ability.

The least improvement regarding COD/agility metrics was the [36], which also had the oldest (and probably more experienced) training group, although it used a mix of the methods employed in the other two studies (strength, plyometrics, and power movements). It was also the shortest study (five weeks), leaving little time to improve. It is possible that as training age increases, more specific training must be done in order for an athlete to progress [36,46]. The fact that strength has increased significantly (1RM Squat, 1RM Lunge) could affect power and RFD [16], but that did not significantly transfer to their COD ability, which could lead to believe that some sort of COD drills could be beneficial. Also, since age is higher larger interference effect could be expected, decreasing training adaptations, especially on explosive strength-related parameters [40,65] when compared to other younger study cohorts.

Firstly, all of the studies either employed a different combination of training modalities (plyometrics and speed or strength and endurance). Also, training ages were different, and so the tests used to access change of direction or agility, which makes it harder to obtain a final conclusion. It would be interesting to see strength values in [34] and compare them to the other two. Not measuring the maturation status also has a downside because maturation can have a big influence on increases in performance [47]. For future investigations, COD deficits could be measured more precisely to access changes in COD ability, and if standardized, would simplify compressions between studies.

Finally, a mix of strength, plyometric, and specific COD drills would be a good combination to increase COD abilities, increasing the volume of more specific drills has training age increases but not using just one modality exclusively, framing the training program according to age, maturation status, and season calendar. The same should occur for time between sessions, mainly for endurance and explosive strength-related training, as the higher the training status, the more separated training sessions should be. In this way, the muscle force adaptations we are trying to impose that can affect COD ability (RFD, power, etc.) are decreased to a lesser degree when concurrent training is imposed. Even in youngsters, where interference might not be a problem, as mentioned above, COD also has a technical component, and learning or perfecting a skill in a fatigued state might also not indicate the best order to maximize learning.

4.2.7. Repeated Sprint Ability

When it comes to repeated sprint ability, two studies [34,36] showed no significant differences in either training order regarding HIT or strength. Also, plyometrics and speed work are done in the same or separate sessions. So, since plyometrics were utilized, running economy might be the common factor between both studies, while the cardiovascular adaptations are probably not. Even though the players in [34] still endured in soccer practice, it was not enough to increase RSA performance since the control group only had a 0.2% difference in RSA. In general, HIT interventions have proven to be beneficial for improving cardiovascular parameters, mainly aerobic power [75]. YYIRT 2 performance is closely linked to an individual's aerobic system [76]. Also, in this study, the HIT training followed the guidelines recommended by [77]. Thus, it seems plausible that the improvement in YYIRT 2 observed in [36] (see Table 3) could be the mechanism by each. RSA times also improved in this same study.

It would be interesting if both studies employed an eccentric utilization ratio or reactive strength index or if both evaluated increases in the stretch-shortening cycle. This way, we could be sure if there was an increase in the SSC and more certainty on running economy. Also, it would be interesting if [34] had employed some sort of cardiovascular test, ideally the YYIRL 2.

Finally, it is possible to see that different training strategies can have similar outcomes in terms of affecting RSA performance, as plyometrics are common to both. Although sprints were the strongest predictor of RSA performance, the increased buildup of metabolites due to increases in power output should be accompanied by other training stimuli (like in [36]), that focus on increases in VO2max and buffer capacity to maximize RSA performance. Therefore, when implementing any sort of HIT work similar to that described above, training order (HIT or STR first) does not seem to cause significant differences. The same does not apply to sprint work, and endurance was mentioned in the sprinting topic but could be done on the same day as plyometrics.

4.3. Study limitations, future research, and practical applications

One of the study limitations is the wide range of experimental designs included and the small number per dimension analysis. Therefore, generalizability cannot be performed with strong consistency. In line with the previous limitations, we suggest that future studies on CT in soccer (both young and adult players) would explore the physical and the physiological effects to confirm previous results.

The methodological quality of the included studies may also represent a risk in interpretations, namely contributing to a heterogeneity of results interpretation for the same dimension of analysis.

Regarding the acute effects of applying concurrent training methods in a real-world scenario, coaches and strength and conditioning practicians should pay more attention to volume, intensity, and proximity to failure the less time between session players have to recover, thereby managing fatigue so that one training does not affect the subsequent one. Also, it seems important to support athletes with proper nutrition between sessions so that performance is not limited by carbohydrate availability or the potential for muscle to grow is not limited by protein intake. Finally, strength training can be used as a means to potentiate the following training session—again, if not taken to failure. It also seems to be a good tool to utilize when teams travel abroad and suffer from jet lag since it has the ability to change the circadian rhythm. On the other hand, when used near sleeping hours, it could potentially affect sleep and, thus, recovery.

AMPK/SIRT1, ER stress, extended muscle damage, and fatigue (neural and peripheral) seem to be mechanisms by each interference is modulated. Therefore:

To reduce the impact of the interference mechanisms, strength training should be done 3-6 hours before or after endurance training. If not possible, athletes should be supported with additional protein and carbohydrates ingestion between sessions.

It seems that HIT or SIT training, such as the methods mentioned in [77], reduces AMPK activity and, therefore, reduces interference [21].

The higher the contraction, such as sprinting and jump training, the more fatigue has an interference since this type of work should be done fully rested. Therefore, RSA (6×30 m with 30'' rest) is not a valid way to train sprinting. However, it is if complete rests are given between sets. So, it is suggested to be done first, whether followed by strength or endurance training.

Volume seems to be the most robust predictor of fatigue, whether in RT or ET. So, variables' volumes should be manipulated according to players' fitness levels and training experience.

When training young players, interference does not seem to play a big role. Nevertheless, when training for technical improvements, fatigue can hinder learning, and so this type of work should be done first.

In addition to the information given before, for future studies, coaches, their staff or practitioners and in order to recommend the practical applications for CT programs, we recommend the following characteristics for resistance/strength training:

- 2 sessions per week of CT;

- begin the strength training with free weights or body weight exercises, without plyometrics;

- the progressive overload principle should be applied with the inclusion of plyometric exercises but without achieving failure;

- switch between upper and lower limb exercises;

- 2-4 sets with a range of 20-4 repetitions, 50-85% of 1 RM per free weight and/or body weight exercise;

- 2-5 sets with a range of 3-10 repetitions per plyometric exercise;

- rest period should allow full recovery to avoid excessive fatigue.

5. Conclusions

Volume seems to be a significant predictor of interference, and endurance seems to be a limiting factor for strength (and not so much the other way around). Team staff must manipulate training variables according to players' age, training experience, fitness levels, rest time between sessions, and nutrition. It is difficult to implement the ideal scenario, but understanding the mechanisms behind interference can help practicians employ the best training program to maximize performance.

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Table 1. Inclusion and exclusion criteria

	Inclusion criteria	Exclusion criteria
Population	Soccer players of any age or sex without injury or illness reported	Others sports than soccer, players with injuries or illness
Intervention	Intervention is CT using strength (e.g., including any type of structured strength training, namely, resistance training, plyometrics, calisthenics) and endurance or sprinting or balance or mobility training	Interventions not including strength and endurance or sprinting or balance or mobility training in the same protocol
Comparator	Compared with control (passive control with just regular field-based training and no other additional program reported) or other intervention group (active control with field-based training and other intervention protocol not consisting in CT, or even single interventions of strength or endurance training)	No compared with passive control or other intervention group
Outcome	At least one pre-post acute and/or a chronic outcome (acute response: immediate response of a physical or physiological variable in response to the exercise; chronic response: adaptations promoted by the training intervention, consisting in permanent changes in physical or physiological variables) related to physiological (e.g., heart rate responses, blood lactate concentrations, oxygen uptake, rate of perceived	No pre-post data related to acute and/or chronic physiological and physical measures

	exertion) and physical (e.g., strength and power, speed, change-of-direction, aerobic capacity) measures	
Study design	The study designs must have at least two groups (randomized or non-randomized).	Descriptive studies or observational analytic.
Additional criteria	Only original and full-text studies written in English	Written in other language than English. Other article types than original (e.g., reviews, letters to editors, trial registrations, proposals for protocols, editorials, book chapters and conference abstracts).

Table 2. Characteristics of the included studies

Study	N	Age (y)	Competitive level	Design	Outcomes	Tests used in the original studies	Measure extracted from the tests in the original studies
(Enright et al., 2015)	15	17.3 ± 1.6 years	Elite	Football players where split in two groups. CT training was employed in both groups 2x/week for 5 weeks, alternating CT order.	Chronic responses: muscle morphology, jumping ability, sprint ability, strength.	- Muscle architecture and muscle thickness - SJ - CMJ - Sprinting speed - Back Squat Strength - Isokinetic strength measurements - Quadriceps maximal isometric voluntary contraction - Isometric loading Rate	- Muscle thickness (cm) - Muscle fascicule angle of pennation (º) - Muscle fascicule length(cm) - Vertical Jump Height (cm) - 10-meter sprint time (s) - 30-meter sprint time (s) - Back Squat Load Lifted (kg) - Peak Isometric Force (N) - Isometric Loading Rate - QuadCon60 - QuadCon180 - QuadEcc120 - HamCon60 - HamCon180 - HamEcc120 - Hecc/Qcon60 - Hecc/Qcon120
(Enright et al., 2017b)	21	26 ±0 4	English “Championship”	10week observational	Acute responses:	Observational study.	- Football-specific Start Time

				study. Internal data (sRPE-TL and heart rate data) and external load (gps, volume RT), training modality frequency and dietary intake.	Internal load, external load.	Heart Rata data GPS Data Training Load RT Volume Load RT Training Intensity (1RM Based)	- Football Duration (m) - HRmax 85%-100% (min) - Average sRPE-TL (AU) - sRPE (AU) - Total Distance travelled (m) - RT start time - RT Duration (m) - RT Volume load (kg) - Frequency of upper body training (n) - Frequency of lower body training (n) - Frequency of lower and upper body training (n) - Frequency of sessions at 4RM, 5RM,6RM, 8RM, 10RM and 12RM (n) - Recovery range between bouts (min) - Recovery period between bouts (min)

(Enright et al., 2018)	13	CG= 17.6 (0.4). CDG = 17.8 (0.8) CWG = 17.8 (0.6)	English Premier League	Athletes where taken twice a week (Monday, Thursday) to the laboratory in two consecutive weeks. Week 1, baseline testing, week 2, two different CT trails were employed (CT1 and CT2). Before, during and after each trail, venous blood samples were collected for each participant.	Acute responses: Hormonal response	-Venous Blood Samples	- Serum growth hormone (ug/L) - Total Testosterone (mmol/L) - Cortisol (mmol/L)

(Kargarfard et al., 2020)	24	17,7 (0,6)	Second division, Iran League	All groups (one control group) attended to technical/tactical soccer training. Additionally, CWD performed on Tuesday plyometric training and on Saturdays Speed training. The CDG training all three modalities in the same session (Saturdays). The duration of this intervention was 6 weeks	Chronic responses: agility ability, sprint ability, power endurance	-505 COD Test -Repeated Sprint Ability Test	- Agility time (s) - 30 m sprint time (s) - Sprint decay
(Kotzamanidis et al., 2012)	35	COM 17,0±1,1	Healthy male volunteers (Con Group) and	During 13 weeks, two groups of	Chronic responses: Strength, sprint	-1RM Squat - 1RM Step up - 1RM Leg Curl	- Squat load lifted (kg)

		STR 17,1±1,1 Con 17,8±0,3	soccer players (COM and STR groups)	followed 2 different training programs, one consisting conventional strength training (STR), the other consisting in combining conventional strength training and running speed training in the same session (COM).	ability, jumping ability.	- 30m Sprint -Squat Jump -Countermovement Jump -Drop Jump 40 cm	- Step up load lifted (kg) - Leg Curl load lifted (kg) - 30-m sprint time (s) - Jump height (cm)
(Makhlouf et al., 2016)	57	13,7 ± 0,5	First Division Tunisian	For 12 weeks 3 groups trained in different training sequence. Strength before endurance (SE)	Chronic responses: Aerobic capacity, strength, jumping ability, power, agility ability.	Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) - Progressive maximal field test (Vam-eval, VAM) -Bench Press 1RM Test	- Maximal high-intensity intermittent endurance running capacity (m) - Maximal aerobic speed (km/h) - Bench Load lifted (kg) - Squat Load Lifted (kg)

				in a single session, endurance before strength (ES) in a single session, both 2/week and strength and endurance on alternate days (ASE) (4x/week) .		-Squat 1RM Test Countermovement Jump Test (CMJ) -Squat Jump Test (SJ) - 5 Jump Test for Distance (5JT) - Medicine ball throw -10 and 30-meter sprint -Agility-15m - Agility-15m with ball	- Jump with countermovement height (cm) - Jump height without countermovement (cm) - 5 jumps distance (cm) - Ball Throw Distance (cm) - Agility 15m time with and without ball (s)
(McGawley & Andersson, 2013)	18	23 ± 4	Professional and semi-professional Swedish I Division	A 5-week with two groups , one would perform HIT followed by Strength (HIT-STR) the other Strength	Chronic responses: Body composition, jumping ability, strength, agility ability, sprint, aerobic capacity, power endurance	-Body composition) -Countermovement Jump (Abalakov) - 3RM Squats (parallel) - 3 RM Lunges/split squat -Maximum repetitions chin-ups	- Body Fat (%) - Fat (kg) - Lean mass (%) - Lean mass (kg) -Jump height (cm) -Maximum load lifted for 1RM Squat (kg) - Maximum load lifted for 1RM Lunges (kg)

				followed by HIT (STR-HIT). CT sessions were carried out 3 times per week (Tuesdays, Thursday and Fridays), 30 minutes of HIT or STR followed by the remaining modality. Soccer technical and tactical field sessions were performed on Mondays and Wednesdays.		-Maximum repetitions Hanging sit up - 40m modified T-Test -Yo-Yo Intermittent Recovery Test Level 2 (YYIRTL2) -10 m sprint - 6x30m repeated sprint test -Soccer specific flexibility test	- Number of repetitions performed Chin ups (n) - Number repetitions performed -Change of direction ability /agility (s) - 10-m sprint time (s) -Distance covered (m) - Sum of 6 sprints (s) - Performance decrement (%) -Iliopsoas - Hamstrings
(Sparkes et al., 2020)	14	22.1 ± 3.1	Semi-Professional	Two CT training order, either SSG training followed by	Acute responses: Hormonal response, power,	- Countermovement Jump (Abalakov) - Bam+ Questionnaire - Saliva samples - RPE - GPS Data	- Jump height (cm) - Peak Power Output (w/kg) - Monitor Fatigue (AU)

				resistance training (SSG + RES) or resistance training followed by SSG, both with a 2-hour interval. Players were given 72 hours of rest between CT sessions. Data was collected before (0 h) and after (24h) in both protocols. Saliva was also collected prior to the second training session (+2h) during both protocols so assess readiness	internal load, external load.		-Mood (AU) - Testosterone (ng/dl) -Cortisol (ng/dl) -Testosterone to Cortisol (AU) - Exercise intensity (AU) - Total distance (m) -HSR (m) -Player Load (AU)

				to undertake the second session of the day)			

Table 3. Characteristics of CT programs in the included studies.

Study	Duration (w)	d/w	Total sessions (intervention)(n)	Total Session (Experimental Intervention + Regular Session)	Strength training	Other training	Type of CT (within or between sessions)	Protocol of strength training	the
(Enright et al., 2015)	5 weeks	2 days/week	10	20 regular soccer sessions + 5 games	Maximum Strength	Soccer Specific Endurance Training	Both groups did CT training in the same day. E+S group had ~120’ difference between session, while S+E group had ~30’-45’ difference.	Strength program consisted in 4 sets of 6 reps (~85% 1RM) of Parallel Back Squat, deadlift, stiff-leg deadlift and front	warm Sided versus Each at an 95%

								lunge. Also 3 sets of 8 reps of the Nordic hamstring was performed.	Betwe 3' of was a size w interva and tactica given. Techn work
(Enright et al., 2017b)	10 weeks	Week 1-3 5 days, 3 days, 3 days a week respectively. Weeks 4-10 1 day a week	17	49 regular session +	Maximum Strength	Specific Soccer Endurance	Resistance training followed by Specific soccer endurance or Specific soccer endurance followed by resistance training. The order was not consistent but always	Upper body only (n = 8) 6 RM, n = 1; 8 RM, n = 3; 10 RM, n = 3; 12 RM, n = 1. Lower body only (n = 4) 6 RM, n = 3; 8 RM, n = 1.	specifi was 10:30, 74 ± 5

				11 games + 17 Strength session			performed on the same day	Full body (n=5) 4 RM, n=1; 5RM, n=3; 8 RM, n=1.	
(Enright et al., 2018)	2 weeks	2 days a week	2	2	Maximum Strength	Soccer Specific Endurance	Soccer Specific Endurance Training followed by Resistance Training with ~105' difference between them or Resistance training followed by Soccer Specific Endurance Training performed in the same day with ~60' difference between them.	The strength training consisted consisted in 4 sets of 6 reps (~85% 1RM) of Parallel Back Squat, deadlift, stiff-leg deadlift and front lunge. Also 3 sets of 8 reps of the Nordic hamstring was performed.	Specif Traini a dyn (~20') games techni work allowe player games posses with a perfor intensi HRma was

									betwe of ac were a
(Kargarfard et al., 2020)	6 weeks	CWG 2 a week CDG 1 per week	CG (n=0) CWG (n=12) CDG (n=6)	CG (n=30) CWG (n=42) CDG (n=36)	-	Plyometric, Speed, Soccer Specific Endurance	CWG group had two types of CT training, on Tuesday, plyometrics and soccer specific endurance and on Saturday speed and soccer specific endurance withing the same session. The CDG group had CT training also on Tuesday and Saturday, but both speed and plyometric were performed concurrently with soccer specific		and C the sa and S the dif was o (CDG week (trainin exerci differe (vertic horizo bilater unilate the ply plyom repetit betwe with

							endurance within the same session.		progre per we or 3 s with 5 consis and 30 startin 2 set and progre for th sprint 30 n betwee for th 45'' fo 60'' fo 10m 180º imploy 10/5/1 with 6

									set w betwee respec progre a set p
(Kotzamanidis et al., 2012)	13 weeks	First period, general and equal to every group (4 weeks), frequency was 3 times per week. The remaining period had a frequency of 2 times per week	18 Sessions	There were no regular soccer training, at least described in the article. Only that they were physically active students or soccer players.	Maximum Strength	Speed Training	Strength training followed by Speed Training withing the same session.	The intensities for each subperiod were 8RM, 6RM and 3RM, respectively. For each selected intensity, 4 sets with 3' of rest between them were given. Loads were increased whenever the subject was able to perform more than the target repetitions.	was doing their subper repetit sprint with a every

(Makhlouf et al., 2016)	12 weeks	2 a week for SE and ES groups. 4 a week for ASE group	SE and ES (n=24) ASE (n=48)	SE and ES + regular training (n=72) ASE + Regular Training (n=96)	Maximum Strength, Hypertrophy, Power	Plyometric, Endurance	Both groups, E+S and S+E performed concurrent training within the same session (Tuesday and Thursday), only a 15’ recovery period separate them. ASE group performed endurance on separate days.	Strength training changed every 4 weeks, ending up with 3 different blocks, being the first two more focused on strength and hypertrophy and the third one more on power development. The first two blocks consisted in a mixture of compound and isolated movements with 3 sets of 10 to 15 reps and 3 sets of 6 to 10 reps respectively. The last block used a	trainin prescr indivic Traini 2 roun of 1 intensi 15’’ p at betwee

								more power development approach including Olympic lifting and plyometrics for 3 sets of 5 to 8 reps.	
(McGawley & Andersson, 2013)	5 weeks	3 per week	15	25 (não contei as de pilates 1x semana devia?)	Maximum Strength and Power	Endurance, Soccer Specific Endurance	Endurance followed by Strength or Strength followed by Endurance within the same session	Strength session on Tuesday and Thursday were gym based compromised 2-3 sets of 5-10 reps with a progression overload on resistance exercises from 75-90% 1RM over the 5-week period. On	Tuesd mix lasting period betwe Thurs involv explos using and n runnin Friday compl rounds

								Friday's sessions were focused on power, explosivity and core development, 3 sets of 3-20 repetitions were completed depending on the exercise, also, exercises were performed in a super-set order.	and 2 player soccer dribbli first 2 3vs3 game pitch a 95%.
(Sparkes et al., 2020)	2	1	1	2	Maximum Strength	Soccer Specific Endurance	Soccer Specific Endurance followed by Strength Training or Strength Training followed by Soccer Specific Training within the same day (2-hour difference)	Strength Training included Back Squat, Romanian Deadlift and Barbell Hip Thrust. All performed at an intensity of 85% of 1RM for 4 sets	perfor 2' rest set to drink w was 24 size go

								of 4 with a 4’ of inter-set recovery. Each exercise was preceded by 2 sets of 4 repetitions at 50% and 70% 1RM.	

Table 4. Assessment of the risk randomized studies included with RoB 2

Study	D1	D2	D3	D4	D5	Overall
(Kotzamanidis et al., 2012)	🟡	🟢	🟢	🟡	🟡	🟡
(Makhlouf et al., 2016)	🟡	🟢	🟢	🟡	🟡	🟡

D1: randomization process; D2: deviations from intended interventions (ITT); D3: missing outcome data; D4: measurement of the outcome; D5: selection of the reported result; Green- low risk; Yellow: some concerns;

Table 5. Assessment of risk of bias in non-randomized trails included with ROBINS-I

Study	D1	D2	D3	D4	D5	D6	D7	Overall
(Enright et al., 2015)	🟢	🟡	🟢	🟢	🔴	🟢	🟡	🔴
(Enright et al., 2017b)	🟢	🟡	🟢	🟢	🔴	🟡	🔴	🔴
(Enright et al., 2018)	🟢	🟢	🟢	🟢	🟢	🟢	🟡	🟡
(Kargarfard et al., 2020)	🟢	🟢	🟢	🟢	🟢	🟡	🟡	🟡
(McGawley & Andersson, 2013)	🟢	🟢	🟢	🟢	🟢	🟡	🟡	🟡
(Sparkes et al., 2020)	🟢	🟢	🟢	🟢	🟢	🟡	🟡	🟡

D1: reaching risk of bias judgements for bias due to confounding; D2: reaching risk of bias judgments in selection of participants into the study; D3: reaching risk of bias judgments for bias in classification of interventions; D4: reaching risk of bias judgments for bias due to deviations from intended interventions; D5: reaching risk of bias judgements for bias due to missing data; D6: reaching risk of bias judgements for bias in measurement of outcomes; D7: reaching risk of bias judgments for bias in selection of the reported result; Green: low risk; Yellow: moderate/serious risk; Red: critical risk

Table 6. Qualitative synthesis and summary measures considering the acute effects of concurrent training methods

Study	Hormonal Response	Strength and Power	Internal Load	External Load
(Enright et al., 2017b)		-	Comparing Average sRPE (AU) for football-specific ET between groups (RT + ET, 7 ± 1; ET + RT, 6 ± 1; P = 0.05) showing a significant difference.	Comparing total distance covered (m) during the football specific ETC between groups (avg. RT + ET, 5942 ± 1057; ET + RT, 6213 ± 958;) showing significant differences.

(Enright et al., 2018)	No main effect between trails regarding Cortisol concentration (mmol/L) (P=0,07). A moderate effect size between conditions at time point 4 (13:45) (ES=-0,95). Time point 1 (8:00h) to time point 2 (9:45h) CT1 Cortisol (mml/L), very large effect (reduction) (ES=2.17). Time point 3 (12:30h) to time point 4 (13:45) CT1 Cortisol (mmol/L), large effect (reduction) (ES=1.24). Time point 4 (13:45h) to time point 5 (15:15) CT1 Cortisol (mmol/L), large effect (reduction) (ES=1.14).			

	Time point 3 (12:30) to time point 4 (13:45) CT1 Cortisol (mmol/L), small effect size (no change) (ES=-0,35). Time point 1 (8:00h) to time point 2 (9:45h) CT2 Cortisol (mmol/L), large effect size (reduction)(ES=1.9). Time point 4 (13:45h) to point 5 (15:15h) CT2 Cortisol (mmol/L), very large effect size (reduction) (ES=2.10) When compared between trails, there was no main effect observed between trails (P=0.22). Between trails there was a moderate effect in time point 3 (12:30h) (ES=0.63).			

	Between trails Testosterone AUC, there was a moderate effect (ES=0.71) (CT1; 300 ± 76 versus CT2; 244 ± 81) No change in Testosterone (mmol/l) pre to post-training in either exercises mode (S; ES=0.04, E; ES=-0.11). Time point 3 (12:30h) to time point 4 (13:45h) CT1 Testosterone (mmol/L), large effect size (reduction) (ES=1.34) (P=0.01). No statistical differences in growth hormone concentration (ug/L) between trails (P=0.21). Between trails comparison Growth Hormone concentration (ug/L) in time			

	point 3 showed a moderate effect (ES=0.82). Between trails comparison Growth Hormone concentration (ug/L) in time point 4 showed a moderate effect (ES=0.72). Between trails comparison Growth Hormone AUC was observed (CT1; 14 ± 11 versus CT2; 5 ± 9; ES= -1.08). Time point 3 (12:30h) to time point 4 (13:45) CT1 Growth Hormone concentration (ug/L), large effect (reduction) (ES= 1.38). Time point 4 (13:45h) to time point 5 (15:15) CT1 Growth Hormone concentration			

	(ug/L), moderate effect (increase) (ES= -0.86). Time point 4 (13:45h) to time point 5 (15:15) CT2 Growth Hormone concentration (ug/L), large effect (ES=-1.08). Time point 1 (8:00h) to time point 4 (9:45) CT2 Growth Hormone concentration (ug/L), moderate effect (ES= -0,77).			
(Sparkes et al., 2020)	Testosterone concentration (pg/ml) on pre (0h) SSG+RES -4.4 (32.5) (trivial, ES=0.07) vs RES+SSG 17.0 (25.3) (small, ES=0.27). Trail difference, moderate effect size (ES= 0.73). Testosterone concentration (pg/ml) on pre (2h) SSG+RES -48.0 (35.9) (moderate, ES=0.89) vs	Jump height (cm) on pre (0h) SSG+RES -2.2 (3.1) (small, ES=0.4) vs RES+SSG -4.1 (2.6) (moderate, ES=0.67). Trail difference -1.9 (3.3), moderate effect size (ES= 0.68). Jump height (cm) pre (24h) SSG+RES -2.6 (4.9) (small, ES=0.49) vs RES+SSG -1.3 (2.0) (small, ES=0.25). Trail	Mood score (AU) in the SSG+RES pre (0h) 8.6 (9.1) AU, moderate effect size (ES=0.72) and pre (24h) 5.3 (11.1) AU small effect size (ES=0.44). Mood score (AU) the RES+SSG pre (0h) 3.2 (11.4) AU, small effect size (ES=0.24) and pre (24h) 4.0 (8.5) AU, small effect size (0.29).	Player total distance (m) between groups (SSG + RES, 4659 ± 611 m;RES + SSG, 4660 ± 583 m), there were similar measurements. Players HSR distance (m) between groups SSG + RES, 65 ± 16 m; RES + SSG,58 ± 13 m) there were similar measurements.

	RES+SSG -33.2 (34.3) (small, ES=0,59). Trail difference, small effect size (ES= 0.42). Testosterone concentration (pg/ml) pre (24h) SSG+RES -1.3 (71.8) (trivial, ES=0.02) vs RES+SSG -14.0 (62.0) (small, ES=0.24). Trail difference, trivial effect size (ES= 0.19). Cortisol concentration (pg/ml) pre (0h) SSG+RES -0.066 (0.279) (small, ES=0.30) vs RES+SSG -0.057 (0.217) (small, ES=0.31). Trail difference, trivial effect size (ES= 0.04). Cortisol concentration (pg/ml) pre (2h) SSG+RES -0.310 (0.192) (large, ES=1.89)	difference 1.2 (5.4) there is a small effect size (ES= 0.33). CMJ relative PPO (W/kg) on pre (0h) SSG+RES -0.84 (2.75) (trivial, ES =0.12) vs RES+SSG -3.53 (2.48) (small, ES=0.5). Trail difference -2.69 (3.30) moderate effect size (ES= 1.03). CMJ relative PPO (W/kg) on pre (24h) SSG+RES -1.95 (3.81) (small, ES=0.31) vs RES+SSG -1.56 (2.30) (small, ES=0.25. Trail difference -0.37 (4.19) trivial effect size (ES= 0.12).	Mood score (AU) RES+SSG vs SSG+RES pre (0h), there is a small effect size (ES=0.52). Mood score (AU) in the RES+SSG vs SSG+RES pre (24h), trivial effect size (ES=0.14) RPE score (AU) between groups (SSG + RES, 7.3 ± 1.0 AU; RES + SSG,7.6 ± 1.1 AU), there were similar measurements.	PlayerloadTM (AU) between group (SSG + RES, 470 ± 72 AU; RES + SSG, 465 ± 75 AU), there were similar measurements.

	vs RES+SSG -0.251 (0.178) (large, ES=1.72). Trail difference small effect size (ES= 0.32). Cortisol concentration (pg/ml) pre (24h) SSG+RES -0.065 (0.208) (small, ES=0.36) vs RES+SSG -0.033 (0.173) (small, ES=0.21). Trail difference trivial effect size (ES= 0.17). T/C ratio (AU) pre (0h) SSG+RES 102.6 (216.9) (small, ES=0,52) vs RES+SSG 112.9 (115.0) (moderate, ES=0.73). Trail difference, trivial effect size (ES= 0.06).			

	T/C ratio (AU) pre (2h) SSG+RES 322.1 (237.7) (large, ES=1.73) vs RES+SSG 261.8 (232.4) (large, ES=1.41). Trail difference small effect size (ES= 0.26). T/C ratio (AU) pre (24h) SSG+RES 35.7 (117.7) (small, ES=0.35) vs RES+SSG -11.0 (98.6) (trivial, ES=0.10). Trail difference, small effect size (ES= 0.43).			

Table 7. Qualitative synthesis and summary measures considering the chronic effects of concurrent training methods.

Study	Strength and Power	Muscle Architecture	Aerobic	Sprinting	Jumping	Change of Direction	RSA
(Enright et al., 2015)	Half back squat 1RM (HBS 1RM) (kg) in both groups, greater magnitude in E+S (19,1%) vs S+E (10,3%) and an effect size of -0.54 and -1.79 respectively. HBS 1RM (kg) S+E pre-test 121.9 (23.9) to post-test 134.4 (22.10) (ES=-0.54). HBS 1RM (kg) E+S pre-test	No group interactions were observed. Whole muscle thickness at either distal (MT-D) (P=0.15) mid (MT-D) (P=0.33) or proximal (MT-P) (P=0.43) and fascicule length (FL-M) (P=0.08). MT-D had a 8,8% increase in the E+S, although not significant.		Significant effect in 10-m sprint time (s) (p=0.02). No effect on training organization on 10 and 30-m sprint time (s) (P=0.09; S+E;0; vs E+S; -0,25). 10-m sprint time (s) S+E pre-test 1.72 (0.65) to post-test 1.72 (0.76). No effect size (0). 10-m sprint time (s) E+S pre-test 1.80 (0.36) to	Squat jump height (cm) significantly improved (P=< 0,01). No difference between groups. Squat jump height (cm) S+E pre-test 38.9 (2.9) to post-test 41.8 (2.4). Large effect size (-1.08). Squat jump height (cm) E+S pre-test 38.0		

	115.7 (10.20) to post-test 137.8 (14.10) (ES= -1.79). Isometric peak force MVC (N) force (P=0.391), quadriceps strength (60º/sCon (P= 0.25), at 180º/s Con (P= 0.16) 120º/s Ecc (P= 0.11) no statistical difference pre to post-test. Isometric loading rate had a significant increased (P= 0.02) with training. Isometric loading rate S+E	Fascicle angle of pentation increased in both groups (P=0,02) (S+E;7.9% , E+S 14.3%). Large effect size in E+S (-1,76), S+E moderate effect size (-0,72).		post-test 1.70 (0.42). Small effect size (0,25). 30-m sprint time (s) S+E pre-test 4.22 (0.23) to post-test 4.21 (0.20). Trivial effect size (0,04). 30-m sprint time (s) E+S pre-test 4.29 (0.73) to post-test 4.19 (0.12). Small effect size (0,19).	(5.7) to post-test 41.1 (5.2). Moderate effect size (-0.56). CMJ height (cm) did not change (P=0.53). CMJ height (cm) S+E pre-test 39.2 (4.7) to post-test 39.2 (3.3). Trivial effect size (0). CMJ height (cm) E+S pre-test 40.7 (1.9) to post-test 41.4 (2.8). Small		

	pre-test 1018 (427) to post-test to 1225 (389). Moderate effect size (-0.5). Isometric loading the E+S pre-test 1185 (316) to post-test to 1508 (295). large effect size (-1.05). Concentric Hamstring torque at 60º/s for the S+E pre-test 108 (18) to post-test 121 (22). Moderate effect size (-0.64). Concentric Hamstring				effect size (-0,29).		

	torque at 60º/s for the E+S pre-test 120 (23) to post-test 143 (25). Large effect size (-0,95). Concentric Hamstring torque at 180º/s for the S+E pre-test 106 (20) to post-test 116 (19). Moderate effect size (-0.51). Concentric Hamstring torque at 180º/s for the E+S pre-test 115 (14) to post-test 128 (21). Moderate effect size (-0,72).						

	Eccentric Hamstring torque at 120º/s for the S+E pre-test 133 (23) to post-test 155 (22). Moderate effect size (-0.78). Eccentric Hamstring torque at 120º/s for the E+S pre-test 156 (21) to post-test 192 (25). Large effect size (-1.55). Concentric hamstring torque at 180º/s (P= 0,03).						

	Concentric Quadriceps torque at 180º/s (P=0,02). Eccentric Hamstring torque at 120º/s (P=0,001). Ratio concentric hamstring/quadriceps torque at 60º/s (P=0,01). Ratio concentric hamstring at 60º/s to eccentric quadriceps torque at 120º/s (P=0,05).						
(Kargarfard et al., 2020)				30-m sprint time (s) CDG, pre-test 4.21 (0.24) to post-test 4.00 (0.07), very likely moderate		COD time (s), CDG, pre 2,67 (0,11) to post 2.56 (0,13), moderate effect (improvement) ((-	RSA time (s) CWG, pre-test 27.02 (1.28) to post-test 26.67 (0.73),

				effect (improvement) (-4.9%, [-7.7 to -2.0%]), ES -0.80 [-1.28 to -0.32]). 30-m sprint time (s) CWG, pre-test 4.29 (0.21) to post-test 4.23 (0.17), possibly small effect (improvement) (-1.5%, [-3.3 to 0.3%]), ES -0.28 [-0.62 to 0.06])). *Likely* small and *very likely* moderate greater LS improvements CWG (2.7%, [0.1		4.2%, [-6.4 to -1.8]), ES -0.94 [-1.47 to -0.41])). COD time (s), CWG, pre 2,80 (0,13) to post 2.66 (0,19) moderate effect (improvements) (-5.0%, [-7.7 to -2.2%]), ES -0.97 [-1.52 to -0.42]) Group COD time (s) differences, CDG and GWC, showed very likely moderate improvements in CDG (4.1%, [1.5 to	possibly a small effect (improvement) (-1.2%, [-3.3 to 0.8]), ES -0.24[-0.64 to 0.16]). RSA time (s) CDG, pre-test 26.48 (1.09) to post-test 26.11 (1.20), possibly a small effect (improvement) (-1.4%, [-3.6 to 0.8%]), ES -0.31 [-0.79 to 0.17]). *Possibly* small greater

				to 5.4%]), ES 0.54 [0.01 to 1.06]) and CDG (6.3%, [2.7 to 10.1%]), ES 1.08 [0.48 to 1.69]) than in CG, respectively. Group sprint time (s) comparison, CDG and GWC, showed likely moderate (3.5%, [0.1 to 7.1%]), ES 0.71 [0.03 to 1.39]) greater improvement observed for the CDG group.		6.8%]), ES 0.79 [0.29 to 1.28]) and CWG (5.0%, [1.9 to 8.3%]), ES 0.85 [0.32 to 1.37]) than in CG. Group COD time (s), CDG and GWC, showed trivial differences (-0.89%, [-4.3 to 2.7%]), ES -0.15 [-0.74 to 0.44]).	improvements in RSA were observed in CDG (1.65%, [-0.8 to 4.2%]), ES 0.36 [-0.19 to 0.91]) and CWG (1.45%, [-0.9 to 3.9%]), ES 0.36 [-0.23 to 0.95]) than in CG. Group RSA time (s) comparison, CDG and GWC, showed trivial differences (0.18%,

							[-2.6 to 3.1%]), ES 0.04 [-0.62 to 0.70]).
(Kotzamanidis et al., 2012)	Squat 1RM (kg) COM pre-test 139.58 (18.14) to post-test 151.66 (20.59). Significant difference. Squat 1RM (kg) STR pre-test 140.45 (15.56) to post-test 154.54 (15.72). significant difference. Squat 1RM (kg) CON pre-test 138.33 (18.14) to post-test 140.41 (13.39). No			30-m sprint time (s) COM pre-test 4.34 (0.17) to post-test 4.19 (0.14). Significant difference. 30-m sprint time (s) STR pre-test 4.33 (0.17) to post-test 4.31 (0.16). No significant difference. 30-m sprint time (s) CON pre-test 4.50 (0.21) to post-test 4.48 (0.20). Showing no	Squat jump height (cm) COM pre-test 25.51 (2.51) to post-test 27.50 (3.36). Showing significant difference. Squat jump height (cm) STR pre-test 25.71 (3.14) to post-test 26.19 (3.14). No significant difference. Squat jump height (cm)		

	significant difference. Step up 1RM (kg) COM group pre-test 64.16 (6.33) to post-test 75.41 (8.38). Significant difference. Step up 1RM (kg) STR pre-test 65.45 (7.56) to post-test 76.36 (7.10). Significant difference. Step up 1RM (kg) CON pre-test 69.16 (5.14) to post-test 71.25 (4.33). Significant no difference.			significant difference.	CON group pre-test 25.80 (2.46) to post-test 26.06 (2.56). No significant difference. Squat jump significantly improved only for COM group ($p < 0.01$) Drop jump o significant difference in all 3 groups. CMJ height (cm) significant difference pre to post COM group.		

	Leg curl 1RM (kg) COM pre-test 50.41 (5.41) to post-test 59.58 (5.82). Significant difference. Leg curl 1RM (kg) STR pre-test 53.63 (6.74) to post-test 62.27 (5.64). Significant difference. Leg curl 1RM (kg) CON pre-test 51.25 (4.33) to post-test 52.50 (5.43). No significant difference.				No Significant changes STR and CON.		
(Makhlouf et al., 2016)	1RM bench load lifted (kg), ES,		MAS velocity (km/h)	10-m sprint time (s) ES pre-test	Squat jump height (cm)	15-m agility time (s) ES	

	pre-test 36.43 (11.55) to post-test 53.93 (21.14), differences pre-post-test. 1RM bench load lifted (kg), SE, between pre-test 49.67 (14.57) to post-test 95.40 (17.78), differences. 1RM bench load lifted (kg), ASE pre-test 31.96 (7.55) to post-test 40.57 (10.45), significant differences. 1RM squat load lifted (kg), ES pre-test 88.93 (17.89) to post-test		ES pre-test 14.61 (1.02) to post-test 15.39 (1.00), significant differences. MAS velocity (km/h) SE pre-test 14.80 (1.11) to post-test 15.50 (1.24), significant differences. MAS velocity (km/h) ASE pre-test 15.00 (0.90) to post-test 15.61 (0.90), significant differences.	2.07 (0.09) to post-test 1.95 (0.10), significant differences pre-post-test. 10-m sprint time (s) SE pre-test 2.08 (0.09) to post-test 1.99 (0.12), showing significant differences. 10-m sprint time (s) ASE pre-test 2.19 (0.09) to post-test 2.04 (0.08), significant differences pre-post-test. 30-m sprint time (s) ES pre-test 4.94 (0.21) to post-test 4.81 (0.24),	ES pre-test 35.28 (4.60) to post-test 38.85 (4.39), no significant differences pre-post-test. Squat jump height (cm), SE between pre-test 33.76 (4.17) to post-test 37.29 (2.97), significant differences Squat jump height (cm) ASE pre-test 31.02 (2.05) to post-test 35.25 (4.43), significant	pre-test 3.74 (0.17) to post-test 3.58 (0.18), showing significant differences. 15-m agility time (s) SE pre-test 3.70 (0.21) to post-test 3.64 (0.22), not showing significant differences. 15-m agility time (s) ASE g pre-test 3.88 (0.19) to post-test 3.66 (0.11),	

	130.93 (29.93), significant differences. 1RM squat load lifted (kg) SE pre-test 95.40 (17.78) to post-test 134.07 (29.15), significant differences. 1RM squat load lifted (kg) ASE pre-test 81.50 (10.60) to post-test 114.14 (18.76), showing significant differences. Significant differences in changes between ES		YYIR1 distance (m) ES pre-test 931 (177) to post-test 1663 (219), significant differences. YYIR1 distance (m), SE pre-test 1034 (308) to post-test 1642 (339), significant differences pre-post-test. YYIR1 distance (m) ASE pre-test 974 (273) to post-test 1505	significant differences pre-post-test. 30-m sprint time (s), SE pre-test 5.02 (0.28) to post-test 4.86 (0.23), significant differences pre-post-test. 30-m sprint time (s) ASE pre-test 5.24 (0.21) to post-test 4.94 (0.20), significant differences. Significant difference between ES and ASE in 10-m (p = 0.01) and 30-m (p=0.05)	differences CMJ jump height (cm) ES pre-test 38.06 (4.65) to post-test 39.01 (4.42), no significant differences. CMJ jump height (cm) SE pre-test 36.60 (3.79) to post-test 39.27 (3.02), significant differences. CMJ jump height (cm ASE pre-test 34.80	showing significant differences. 15-m agility no significant differences in changes pre to post between intervention groups. 15-m agility ball time (s) ES pre-test 4.99 (0.25) to post-test 4.86 (0.17), showing no significant differences.	

	and ASE 1RM bench load lifted (kg). Significant differences in changes between SE and ASE 1RM squat load lifted (kg) g Medball toss distance (cm) ES pre-test 3.71 (0.45) to post-test 3.97 (0.56) significant differences. Medball toss distance (cm) SE pre-test 3.81 (0.40) to post-test 4.01 (0.59) showing significant differences. Medball toss distance (cm) ASE		(306), significant differences. No significant between group (ES, SE, ASE) differences in MAS velocity. No significant between group (ES, SE, ASE) differences in YYIR1 distance (m).	Significant difference between SE and ASE in 10-m (p = 0.05).	(2.12) to post-test 37.58 (4.25), significant differences . 5 jump distance (cm) no significant difference in either group pre to post test	15-m agility ball time (s) SE pre-test 5.15 (0.41) to post-test 4.83 (0.26), showing significant differences. 15-m agility ball time (s) ASE pre-test 5.03 (0.25) to post-test 4.91 (0.28), showing no significant differences . 15-m agility ball no significant	

	pre-test 3.53 (0.41) to post-test 3.86 (0.46) showing significant differences. No significant differences in changes between groups Medball toss distance (cm)					differences in changes pre to post between intervention groups.	
(McGawley & Andersson, 2013)	Squat 1RM (kg) HIT-STR pre-test 99 (15) to post-test 117 (17). ES= 0.98 (0.32). %change 19.7 (11.0).		YYIRTL 2 distance (m) HIT-STR pre-test 769 (105) to post-test 875 (152). ES= 0.73 (0.38).	10-m sprint time (s) HIT-STR pre-test 1.78 (0.05) to post-test 1.76 (0.05). ES= 0.52 (0.39). %change 1.4 (2.8).	CMJ height (cm) HIT-STR pre-test 42.3 (3.5) to post-test 45.2 (4.1). ES= 0.46 (0.35). %change 7.0 (6.0).	Agility time (s) HIT-STR pre-test 9.38 (0.23) to post-test 9.28 (0.23). ES= 0.40 (0.31). %change 1.1 (1.5).	RSA time (s) HIT-STR pre-test 27.7 (0.5) to post-test 27.2 (0.6). ES= 0.45 (0.31).

	Squat 1RM (kg) STR-HIT pre-test 107 (19) to post-test 127 (21). ES= 0.98 (0.32). %change 19.1 (15.6). Lunge 1RM (kg) HIT-STR pre-test 70 (11) to post-test 88 (10). ES= 1.13 (0.32). %change 28.5 (15.7). Lunge 1RM (kg) STR-HIT pre-test 77 (15) to post-test 91 (18). ES= 1.13 (0.32). %change 19.1 (17.0).		%change 15.4 (19.2). YYIRTL 2 distance (m) STR-HIT pre-test 729 (202) to post-test 867 (188). ES= 0.73 (0.38). %change 22.9 (27.2). No significant differences in changes between groups.	10-m sprint time (s) STR-HIT pre-test 1.74 (0.08) to post-test 1.70 (0.04). ES= 0.52 (0.39). %change 2.2 (2.6).	CMJ height (cm) STR-HIT pre-test 44.8 (3.7) to post-test 45.5 (5.0). ES= 0.46 (0.35). %change 1.9 (6.9).	Agility time (s) STR-HIT pre-test 9.30 (0.18) to post-test 9.22 (0.25). ES= 0.40 (0.31). %change 0.9 (1.5).	%change 1.9 (1.5). RSA time (s) STR-HIT pre-test 26.8 (0.9) to post-test 26.6 (0.7). ES= 0.45 (0.31). %change 0.8 (1.7). RSA performance no significant difference in changes between groups RSA performance dec (%)

	Chin Ups repetitions (AU) HIT-STR pre-test 8 (5) to post-test 10 (5). ES= 0.45 (0.23). %change 65.3 (127.4). Chin Ups repetitions (AU) on STR-HIT pre-test 9 (3) to post-test 11 (6). ES= 0.45 (0.23). %change 22.9 (23.8). Hanging Sit ups repetitions (AU) HIT-STR pre-test 21 (6) to post-test 23 (5). ES= 0.42 (0.28). %change 14.5 (21.4).						HIT-STR pre-test 4.7 (1.6) to post-test 3.6 (1.0). ES= 0.88 (0.64). %change 19.6 (35.1). RSA performance dec (%) STR-HIT pre-test 5.2 (1.1) to post-test 4.2 (1.3). ES= 0.88 (0.64). %change 16.8 (29.8).

	Hanging Sit ups repetitions (AU) STR-HIT pre-test 22 (4) to post-test 23 (2). ES= 0.42 (0.28). %change 9.7 (11.0).						

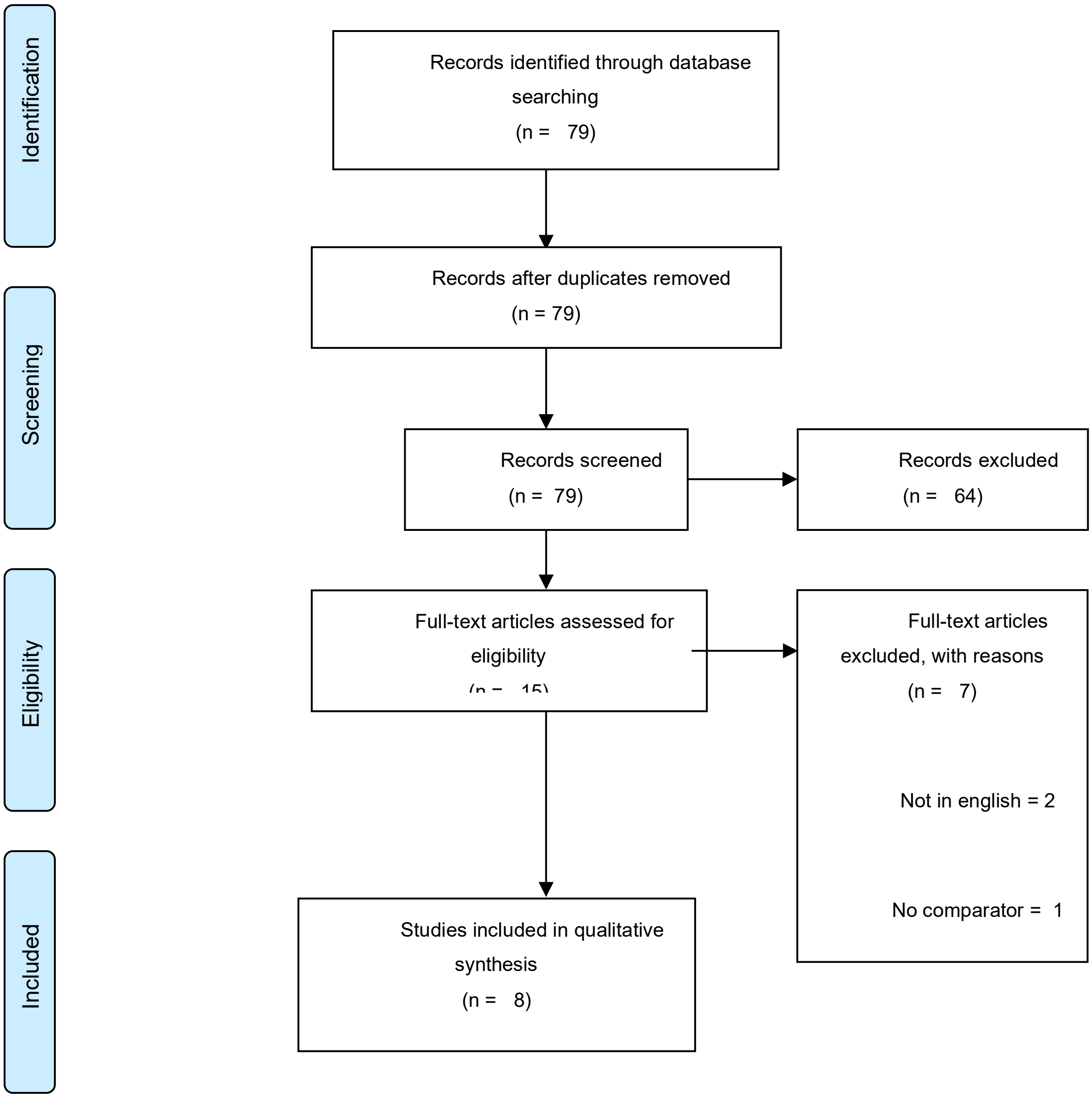

Figure 1. PRISMA flow diagram highlighting the selection process for the studies included in the current systematic review.

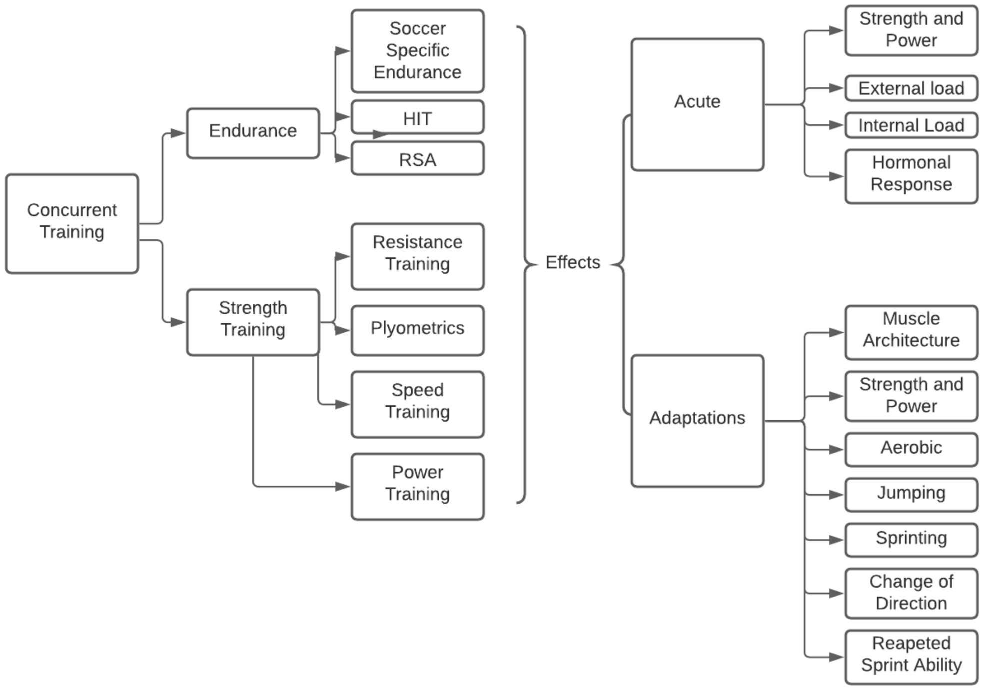

Figure 2. Concept map.

Paper 2

Methodological characteristics, physiological and physical effects and future directions for velocity-based training in soccer: A systematic review

Jorge Ribeiro, José Afonso, Miguel Camões, Hugo Sarmento, Mário Sá, Ricardo Lima, Filipe Manuel Clemente

Methodological characteristics, physiological and physical effects and future directions for velocity-based training in soccer: A systematic review

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Declarations

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Authorship Contributions: JR and FMC lead the project, ran the data search and methodological assessment, and wrote and revised the original manuscript. MC, MS and RL, revised the original manuscript. JA ran the data search and methodological assessment and wrote and revised the original manuscript. HS executed the methodological assessment, wrote and revised the original manuscript.

Abstract

Objective: This systematic review was conducted to: (1) characterize the main elements of VBT studies (e.g., training protocols) conducted in soccer; (2) summarize the main physiological and physical effects of VBT on soccer players; and (3) provide future directions for research. **Methods:** A systematic review of Cochrane Library, EBSCO, PubMed, Scielo, Scopus, SPORTDiscus and Web of Science databases was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. **Results:** The database search initially identified 127 titles. From those, five articles were deemed eligible for the systematic review. Of those, two studies used traditional strength training approach, while the other remaining three used sprint training either resisted or combining resisted and unresisted sprints. All studies addressed strength and power and sprint outcomes, three measures jump performance improvements and only study addressed spatiotemporal and kinematics or aerobic measures, regarding adaptations to VBT interventions. Only one study addressed acute responses to VBT training regarding spatiotemporal variables and kinematics. **Conclusions:** Acute responses to VBT training were that, when sprint time is decreased by at least 50% to 60%, sprint kinematics are immediately affected, but spatiotemporal variables are only significantly affected when velocity loss achieves at least 60%. For long term adaptations, it seems that for strength increases using the squat higher or lower velocity loss due to in-set fatigue accumulation does not make a difference, but it does when it comes to jump performance, favoring the low v.loss groups (15%). The same applies form sprint, low v.loss accumulation due to fatigue along sets seems to be detrimental to sprint performance adaptations. Also high v.loss during sprints due to external load can positively impact sprint performance improvements without arming running technique has previously thought. **Keywords:** football; athletic performance; strength training; resistance training; velocity-based training.

1. Introduction

Velocity-based training (VBT) is a modern, precise and objective method of prescribing resistance training programs, and provides a way of accessing training intensity and volume (J. Weakley et al., 2021). Traditional ways of prescribing training intensity was throw a percentage of 1 repetition maximum (%1RM) (Fry AC, 2004) or throw some sort of auto perception like rate of perceived exercitation (RPE) (Borg, 1970) or reps in reserve (RIR) (Zourdos et al., 2016), or even a combination of them all. But there are some issues with the methods presented above. For example, %1RM does not take into account weekly strength fluctuations (Galiano et al., 2020), improvements in strength during the mesocycle (J. J. González-Badillo & Sánchez-Medina, 2010), readiness (Fernando Pareja-Blanco et al., 2017), or even individual differences for some exercises such has the squat (Cooke et al., 2019a) . For example, in a study by Pareja-Blanco (Fernando Pareja-Blanco et al., 2017), were players endured in 18 RT sessions for 6 weeks, it is possible to observe, mainly in VL15 group, an "unstable" theoretical 1RM, more specifically from session 1 to 10.

Probably using RPE, alongside %1RM based training, increases the autoregulation, but still, has is flaws. RPE, accounts for the perception of an individual at a given time, that can be negatively or positively affected by many factors such has music, caffeine, personality, temperature and so on, affecting the athlete's judgment (Haddad et al., 2017). RPE can be also less when further an athlete is from failure (Hackett et al., 2017b), such has the ones present in speed and power training, leading to a less accurate exertion gauge and therefore monitoring. For example in the study by Hackett (Hackett et al., 2017b) showed when actual repetitions to failure (ARF) or estimated repetitions to failure (ERF), were above <= 3 and/or <5, respectively, accuracy progressively decreases. Also in a meta-analysis by Doherty (Doherty & Smith, 2005),with 202 studies included, they accounted for the effects that caffeine had during and after exercise on RPE, concluding that caffeine improved exercise performance, and that RPE accounted for 29% of the variation in increased performance, by increasing the capacity to tolerate discomfort.

When it comes to the majority of sports, powerful and explosive athletes, can have an competitive advantage (Suchomel et al., 2016a). Specifically soccer, explosive actions, are the ones that can decide the outcome of the game (Faude et al., 2012; T. A. Haugen, Tønnessen, Hisdal, & Seiler, 2014), therefore it seems important that coaching staff improve those explosive abilities throw a well design strength and condition program, that surfs the force-velocity curve, from low velocity high force movements such has heavy squats, to moderate force and velocity like weighted jump squats with various weights all the way to high speed low force such has plyometric jumps and sprints. It is also important that the training plan is individualized to athletes' abilities, readiness and able to better control the fatigue imposed during this type of sessions, manly during the season, where due to congested schedules, athletes al already exposed frequent games. But, to implement this, with a big team squad such has soccer, with limited coaching staff to control every athletes set, and with all the caveats associated with %based training RPE or repetitions in reserve (RIR), and individual differences, VBT may better account for all those issues. Not only it is an objective data that can easily be individualized, by applying precise measures related to which part of the strength curve you want to simulated, to auto-regulate according to the one's readiness (Nevin, 2019) , level of fatigue imposed (proximity to failure/individual minimum velocity threshold (MVT) and/or velocity drop (V.Drop)) (J. Weakley et al., 2021). It also can improve athlete's motivation ("Velocity Based Training - Science for Sport," n.d.; J. J. S. Weakley et al., 2019), track progression in a more objective way than the RPE/RiR due to above factors. In the study by Weakly (J. J. S. Weakley et al., 2019) athletes were exposed to the same protocol twice, a set of 10 repetition back squat, all of them being measured by a GymAware, were the group that had feedback had an almost certain greater mean concentric velocity, when accounting for all repetitions. Another study by (J. Weakley, Wilson, et al., 2020) leads to the same conclusions, with a similar test set up. 10 repetitions were each trail included either verbal or visual kinematic or verbal encouragement feedback, with no differences no significant differences between feedbacks, but all better than the control group, that had no feedback.

VBT effects were also study in soccer, such has different velocity loss (15% (VL15) vs 30% (VL30)) in trained soccer players, were they observed the outcomes in the such has 1RM, countermovement jump (CMJ), Yo-Yo Intermittent Recovery Test (YYIRT) and 30-sprint, finding a better improvements for VL15 group in CMJ and a likely positive effects in the 1RM (Fernando Pareja-Blanco et al., 2017). Loturco (Loturco et al., 2015) study the effects of increasing bar velocity (IGV) or reducing (RGV) (20% for each group), during 6 sets of 6 repetitions on squat jump, finding that RGV experienced better results in the leg press 1RM, but IGV had more favorable increases in Zig-Zag Change of Direction Speed, and 20-m sprint speed at all distances (5, 10 and 20-meters) whereas RGV on had improvements at 20m, leaving CMJ with no significant differences in changes between groups.

Considering the growing number of VBT studies conducted in soccer and the relevance for practice, there is a need for a systematic review that may help to characterize the experimental VBT protocols in soccer players and a general overview of the physiological and physical effects on the players. A scoping review may help to achieve an overview about the possibilities for application of VBT on soccer, as well as help to define future research and intervention directions. Therefore, the aim of this scoping review was threefold: (1) characterize the main elements of VBT studies (e.g., training protocols) conducted in soccer; (2) summarize the main physiological and physical effects of VBT on soccer players; and (3) provide future directions for research.

2. Methods

This systematic review followed the Cochrane Collaboration guidelines (Higgins et al., 2019). The scoping review strategy was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines (Page et al., 2021).

2.1. Eligibility criteria

The P.I.C.O.S. (Population or problem; Intervention or exposure; Comparison; Outcome; Study design) is: P (healthy soccer players of any age or sex); I (VBT training protocols); C (preferably, comparator groups using non-VBT based training, but not mandatory); O (acute and/or chronic responses: biochemical, physiological and physical); S (multiarm, either randomized or non-randomized).

The inclusion and exclusion criteria based on PICOS can be found in table 1.

<TABLE 1

2.2. Information sources

Electronic databases (Cochrane Library, EBSCO, PubMed, Scielo, Scopus, SPORTDiscus and Web of Science) were searched for relevant publications on April 13, 2021 An additional search within the reference lists of the included records was conducted to retrieve additional relevant studies. An external expert was contacted in order to verify the final list of references included in this systematic review, in order to understand if there was any study that was not detected through our research. Possible errata for the included articles were considered.

2.3. Search strategy

Free text terms were entered in various combinations in the title or abstract: (“Soccer” OR “Football”) AND (“velocity-based” OR “VBT”). In EBSCO and Scielo, the combination of title and abstract is not available. Instead of conducting multiple searches, the search was expanded to “all fields”.

2.4. Selection process

The screening of the title, abstract and reference list of each study to locate potentially relevant studies was independently performed by the two authors (FMC and JA). Additionally, they reviewed the full version of the included papers in detail to identify articles that met the selection criteria. A discussion was made in the cases of discrepancies regarding the selection process with a third author (J.R.).

2.5. Data collection process

A data extraction was prepared in Microsoft Excel sheet (Microsoft Corporation, Readmon, WA, USA) in accordance with the Cochrane Consumers and Communication Review Group's data extraction template (Group, 2016). The Excel sheet was used to assess inclusion requirements and subsequently tested for all selected studies. The process was independently conducted by the two authors (FMC and JA). Any disagreement regarding study eligibility was resolved in a discussion. Full text articles excluded, with reasons, were recorded. All the records were stored in the sheet.

2.6. Data items

The main outcomes defined for data extraction were: (i) acute or immediate effects related to VBT exposure (internal load, external load, hormonal responses and strength and power); and (ii) adaptations related to VBT interventions (pre-post differences in strength and power, muscle architecture, aerobic performance, sprinting, jumping, change-of-direction [COD] and repeated sprint ability [RSA]). The acute or immediate effects are related to immediate and transitory effects of VBT in internal load (e.g., psychophysiological responses (Impellizzeri et al., 2019b), e.g., heart rate, rate of perceived exertion [RPE], blood lactate), external load (e.g., physical demands related to the exercise (Impellizzeri et al., 2019b), e.g., distances covered at different speed thresholds, accelerations, decelerations), hormonal responses (e.g., testosterone, growth hormone) and strength and power (e.g., vertical jump height using tests as squat, countermovement or drop jumps). The adaptations represent a structural change in fitness status in which the following measures were extracted: (i) strength and power (e.g., repetition maximum); (ii) muscle architecture (e.g., changes in fascicle angle, muscle thickness); (iii) aerobic performance (e.g., maximal oxygen uptake, distance in field-based tests); (iv) sprinting (e.g., time in specific distances, as 10-, 20-, 30-meters); (v) jumping (e.g., vertical jump in testes as squat, countermovement or drop jump; horizontal jumps); (vi) COD (e.g., time in tests as 5-0-5, pro-agility, T-test); and (vii) RSA (e.g., time or fatigue index in tests of repeated-sprints in different distances).

In addition to the main outcomes, the following information was extracted: (i) type of study design, number of participants (n), age-group (youth, adults or both), sex (men, women or both), competitive level (if available), and type of original articles included (study design).

2.7. Study risk of bias assessment

The version 2 of the Cochrane risk-of-bias tool for randomized trials (RoB2) (J. A. C. Sterne et al., 2019) was used to assess the risk of bias in the included randomized-controlled trials. Five dimensions are inspected in this assessment tool: (i) bias arising from the randomization process; (ii) bias due to deviations from intended interventions; (iii) bias due to missing outcome data; (iv) bias in measurement of the outcome; and (v) bias in selection of the reported result. Using RoB2 a qualitative synthesis was performed.

Two of the authors (JA and HS) independently assessed the risk of bias. Any disagreement in the rating was resolved through discussion and by a third author (FMC).

The Cochrane risk of bias in non-randomized studies of interventions (ROBINS-I) was used to assess the risk of bias in included non-randomized intervention studies (J. A. Sterne et al., 2016). Three domains are analyzed in this assessment tool: (i) pre-intervention (bias due to confounding; bias in selection of participants into the study); (ii) at intervention (bias in classification of interventions); and (iii) post-intervention (bias due to deviations from intended interventions; bias due to missing data; bias in measurement of outcomes; bias in selection of the reported results). Two of the authors (JA and HS) independently assessed the risk of bias. Any disagreement in the rating was resolved through discussion and by a third author (FMC).

2.8. Effect measures

Mean and standard deviation of the absolute and relative measures will be collected and represented in summary tables.

3. Results

3.1.Study selection

The searching of databases identified a total of 127 titles. These studies were then exported to reference manager software (EndNote™ 20.0.1, Clarivate Analytics, Philadelphia, PA, USA). Duplicates (77 references) were subsequently removed either automatically or manually. The remaining 50 articles were screened for their relevance based on titles and abstracts, resulting in the removal of a further 42 studies. Following the screening procedure, 8 articles were selected for in depth reading and analysis. After reading full texts, a further 4 studies were excluded due to not meet the eligibility criteria regarding intervention (Franco-Márquez et al., 2015; Juan J. González-Badillo et al., 2015) or comparators (Lazarus, Halperin, Vaknin, & Dello Iacono, 2021; Ramírez, Núñez, Lancho, Poblador, & Lancho, 2015). Four studies were deemed eligible for qualitative analysis: three randomized studies (Grazioli et al., 2020; Loturco, Ugrinowitsch, Tricoli, Pivetti, & Roschel, 2013b; Fernando Pareja-Blanco et al., 2017) and one non-randomized study (Lahti et al., 2020). A manual search within their reference list suggested four titles of interest, of which three were excluded upon analysis of the abstracts (Bachero-Mena & González-Badillo, 2014; Cahill et al., 2019; Loturco et al., 2020), but one randomized study was included in the final sample (J.-B. Morin et al., 2017). Due to the small number of studies and their heterogeneity, meta-analysis was not performed.

< FIGURE 1

3.2.Study characteristics and training protocols

The characteristics of the included studies can be found in Table 2. Of all the studies included in this review(Grazioli et al., 2020; Lahti et al., 2020; Loturco, Ugrinowitsch, Tricoli, Pivetti, & Roschel, 2013a; J.-B. Morin et al., 2017; Fernando Pareja-Blanco et al., 2017) are made in a young adult population and athletes chronic response, varying on the competitive level at which they played. Loturco (Loturco et al., 2013b) and Grazioli (Grazioli et al., 2020) sample was from professional Brazilian players, being the first in elite. Other two (Lahti et al., 2020; Fernando Pareja-Blanco et al., 2017) sample was from

Finland Premier League and highly trained soccer players respectively. Finally Morin (J.-B. Morin et al., 2017) intervention was in a group of amateur players.

<TABLE 2

The details of the interventions and training protocols can be found in Table 3. All the studies included (Grazioli et al., 2020; Lahti et al., 2020; Loturco et al., 2013b; J. B. Morin et al., 2017; Fernando Pareja-Blanco et al., 2017) some form of velocity based training. Loturco and Lathi (Loturco et al., 2013a) used it to has a form of evaluation form the correct weight to prescribe for the jump squat, but not using it during the training intervention to adapt load if necessary. Lathi (Lahti et al., 2020) also has a mean to prescribe, but if adjustments were made during training intervention wasn't described by the authors. All others (Grazioli et al., 2020; J. B. Morin et al., 2017; Fernando Pareja-Blanco et al., 2017) used VBT both for prescription and auto-regulation standpoint during intervention.

Three studies (Grazioli et al., 2020; Lahti et al., 2020; J. B. Morin et al., 2017) included resisted sprints has their exercise intervention, of which, only (Lahti et al., 2020; J. B. Morin et al., 2017) combined with unresisted sprints, all of them focused on sprint speed outcomes, varying different splits ranging from 5-m up to 30-m. Loturco and Pareja-Blanco (Loturco et al., 2013a; Fernando Pareja-Blanco et al., 2017) used the Back Squat and jump squat (only on first study) to access changes in performance in jump, sprint and also cardiovascular adaptations (Pareja-Blanco study only). Intervention training frequency varied form 1x/week but with the longest duration, 11 weeks, (Grazioli et al., 2020) up to 3x/ week from Pareja-Blanco (Fernando Pareja-Blanco et al., 2017) but with the shortest duration has in Loturco (Loturco et al., 2013a), both lasting 6 weeks .

<TABLE 3

3.3.Risk of bias in studies

The randomized studies were assessed using RoB 2 instrument (table 4). Among the included studies, three were scored with some concerns (Grazioli et al., 2020; Loturco et al., 2013b; Fernando Pareja-Blanco et al., 2017) and one with risk of bias (J.-B. Morin et al., 2017). The dimensions of randomization process and selection of the reported result were the items with great concerns.

<TABLE 4

The non-randomized study (Lahti et al., 2020) was assessed using the ROBINS-I (table 5). The article was scored with critical risk of bias in the items: (D1) reaching risk of bias judgements for bias due to confounding; (D5) reaching risk of bias judgements for bias due to missing data; and (D6): reaching risk of bias judgements for bias in measurement of outcomes.

<TABLE 5

3.4. Results of individual studies: Acute (Immediate) effect

The of results about the acute effects of VBT in kinematics and spatiotemporal variables can be found in Table 6. Only one study (Lahti et al., 2020) followed the immediate response of different velocity loss due to resisted sprints. Both intervention groups had significantly change their kinematics, but only HS60% group also significantly changed their spatiotemporal values (contact time, step rate and step length). The results regarding acute variables are inserted in the same table has the chronic, due to only small amount of variables and studies, they are addressed has "Immediate" on the spatiotemporal and kinematic tab.

3.5. Results of individual studies: Chronic (Adaptation) response

The synthesis of the results regarding the effects of VBT on chronic adaptation (i.e., strength and power, sprint, jump, aerobic) can be found in Table 6. All the randomized studies (Grazioli et al., 2020; Lahti et al., 2020; Loturco et al., 2013b; J.-B. Morin et al., 2017; Fernando Pareja-Blanco et al., 2017) measured strength and power outcomes. Two of those (Loturco et al., 2013b; Fernando Pareja-Blanco et al., 2017) used squat movement patterns, attaining Squat 1RM in both studies, were in Loturco (Loturco et al., 2013a) no significant difference in changes between groups was found, whereas in Pareja-

Blanco (Fernando Pareja-Blanco et al., 2017) there was a slightly higher tendency for low velocity loss group to improve Squat 1RM and also Average Mean Propulsive Velocity (AMPV). Loturco (Loturco et al., 2013a) also looked at power metrics, were no difference in changes between groups regarding Back Squat Mean Power (BS-MP) and Squat Jump Mean Power (SJ-MP). The other three studies (Grazioli et al., 2020; J.-B. Morin et al., 2017) used sprints, whether resisted (sled) of unresisted, were strength outcomes were used such has Isometric Peak Torque in Grazioli (Grazioli et al., 2020), were there was decrease in both groups with no significant difference but not in Morin and Lahti (Lahti et al., 2020; J.-B. Morin et al., 2017) were maximal theorical force (F0) and maximal theorical effectiveness of directing force forwards in the first step (RFmax) increased. Only in Lahti (Lahti et al., 2020) velocity (v0) increased, in one of the groups.

Sprint performance was accessed in all the studies included (Grazioli et al., 2020; Lahti et al., 2020; Loturco et al., 2013a; J.-B. Morin et al., 2017; Fernando Pareja-Blanco et al., 2017). Morin (J.-B. Morin et al., 2017) observed positive effects on 5-m sprint time and the same happened in Lahti study (Lahti et al., 2020) but only in HS50% group, with the caveat that could be due to weekly performance fluctuations alongside with measurement error, not surpassing the minimal detectable threshold. Regarding the 10-m sprints all three (Grazioli et al., 2020)studies (Grazioli et al., 2020; Lahti et al., 2020; Loturco et al., 2013b) had a positive effect improvements, with a tendency for the lower velocity loss group to have a better outcome (Grazioli et al., 2020; Lahti et al., 2020). 20-m sprints follow the same trend, with the three studies (Grazioli et al., 2020; Lahti et al., 2020; J.-B. Morin et al., 2017) able to impose positive adaptations in the intervention groups, being that Grazioli's (Grazioli et al., 2020) had a tendency for better improvements in lower velocity loss groups (G10). In the 30-m distance only one study

(Lahti et al., 2020) had positive outcomes, in contrast with Pareja-Blanco and Loturco (Loturco et al., 2013b; Fernando Pareja-Blanco et al., 2017).

When it comes to jump performance, three studies (Grazioli et al., 2020; Loturco et al., 2013b; Fernando Pareja-Blanco et al., 2017). Two of them (Loturco et al., 2013b; Fernando Pareja-Blanco et al., 2017) had positive effects, but with a caveat that only VL15 in Pareja-Blanco (Fernando Pareja-Blanco et al., 2017) improved CMJ. In contrast, Grazioli (Grazioli et al., 2020) found decrements in jump performance in both intervention groups.

Only one study (Fernando Pareja-Blanco et al., 2017) addressed aerobic component, with significant improvements pretopost with no difference between intervention.

Finally, one study (Lahti et al., 2020) accessed the impact of different velocity loss in sprints on kinematics and spatiotemporal variables, finding pretopost differences only on HS60% but not in HS50%.

< TABLE 6

A conceptual overview elaborated by the authors of this scoping review can be seen in Figure 2. This overview aims to systematize the complexity of the field and presenting it in an intelligible manner.

< FIGURE 2

4. Discussion

This systematic review presents the effects of velocity-based training used in a more traditional strength training and in resisted sprints and its impact in a soccer context, either in acute responses or chronic adaptations.

4.1. Discussion of evidence: acute effects

4.1.1. Kinematic and Spatiotemporal

Only the study by Lathi (Lahti et al., 2020)had access to kinematic and spatiotemporal variables such has the ones seen in table 2. The heavier group (HS60 %) had significantly increased all spatiotemporal variables (contact time, step rate and step length) and some kinematic variables (touchdown CM distance and CM angle at touchdown), whereas the lighter group (HS50%) only affected kinematic variables (touchdown CM distance and CM angle at touchdown). This difference in spatiotemporal variables although, not a driver for increase in performance, may be a useful tool for coaches to teach their athletes how to push/create force against the ground and project themselves, with the right cues, since they spent more time on the ground at each step allowing them also more time improve that skill, using a movement pattern very similar to the unresisted acceleration phase.

Kinematic variables also had an immediate response to resisted sprints. CM touchdown distance and CM angle at touchdown which led to taking steps further behind the CM, but with no carry-over to changes at them of the intervention during unresisted sprints.

More research using a heavy load, that induces significant velocity decrement, also according to the individuals load-velocity profile is needed.

4.2.Discussion of evidence: adaptations

4.2.1. Strength and Power

All the studies in this review (Lahti et al., 2020; Loturco et al., 2013b; J.-B. Morin et al., 2017; Fernando Pareja-Blanco et al., 2017) had a positive outcome in terms on strength with the exception of (Grazioli et al., 2020). Has Loturco and Pareja-Blanco

(Loturco et al., 2013b; Fernando Pareja-Blanco et al., 2017) used the squat exercise has their training intervention and also their exercise test to access strength improvements, therefore, it is expected that either due to neuromuscular adaptations or increased squat ability or a combination of both, their squat 1RM would increase. Another study by the same author (F. Pareja-Blanco et al., 2017) compared the effects of the same training intervention but with two different velocity loss (V.Loss), 20% (VL20) and 40% (VL40%) in various outcomes one of them being strength. Their results are in line with the one reviewed in this paper, finding no significant differences between groups in strength adaptations. The other three studies (Grazioli et al., 2020; Lahti et al., 2020; J.-B. Morin et al., 2017) used different exercise in their intervention groups and means to access strength adaptations. Morin (J.-B. Morin et al., 2017) used 80% of athletes body weight (BW) and Lahti (Lahti et al., 2020) 94% for HS50% and 120% for HS60% groups, whereas, Grazioli used loads between 45-65% which are considerably more light than the other studies. This difference in loads might possibly allow the heavier groups to spend more time one the ground (like what happened in Lahti (Lahti et al., 2020) and discussed in chapter 4.1.1), and therefore giving more time to the athletes achieve their peak force, stimulating strength increases. In fact, the first steps of the acceleration are considered to be more dependent on maximal strength (Kawamori, Nosaka, & Newton, 2013), thus this relationship could theatrically work in both direction, especially on this early acceleration phase is heavily resisted such has in Morin and Lahti (Lahti et al., 2020; J.-B. Morin et al., 2017) studies.

It is know that resistance training can improve power out (Baker, 2001; Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997), in the reviewed studies, whether from a squat exercise (Loturco et al., 2013b) or resisted sprints (Lahti et al., 2020), interventions had a positive adaptation on power. Loturco used based on max strength

(%) achieved by and Lahti based on max speed (VBT) to improve that physical quality. In Lahti (Lahti et al., 2020) study, power (Pmax) as significantly greater in the HS50% group in comparison with the control, and was considered the main driver for improve sprint ability, showing a clear favoritism. Optimal load that maximizes power output is extremely variable, according to the exercise and athlete and their training status for example, therefore, might be important so access the individual load for each athlete in each exercise (Kawamori & Haff, 2004). The usage of VBT to create a individualize force-velocity profile, for the squats or sprints should be a good recommendation for strength and conditioning coaches, if they want to maximize power output.

Finally, it would be interesting to have isometric measurements alongside squats 1RM so see how much strength came from neuromuscular adaptations and exercise proficiency. Also it would be for best interest to standardize velocity based training approach, for example in Loturco (Loturco et al., 2013a) increases or decreases in velocity throughout the second part of the intervention was based on %1RM, instead of adjust load according to the individual load-velocity profile (FVp), or a standardize velocity (ex: between 0,5-0,6 ms).

4.2.2. Sprint

At the other end of the spectrum, sprint, had a better increases when less velocity was loss during a set (Fernando Pareja-Blanco et al., 2017) in the squat, velocity stop throw out multiple sets during resisted sprints (Grazioli et al., 2020) or relative to their maximum ability (Lahti et al., 2020), HS50% and HS60% groups, were only HS50% had significant differences in changes relative to control group, a better stimulus across the acceleration phase and overall favoritism to improve sprint ability. Indeed, fatigue accumulation seems to be detrimental for velocity outcomes. in Grazioli (Grazioli et al., 2020) here both groups performed sprints until a relative low velocity loss was achieved, 10% G10 and 20% the G20 group, there were greater improvements for the G10 in the 10 and 20-m sprint time, even though the G20 completed more sprints. Also, and although there is still debatable the percentage of which the minimum intensity is required to stimulate speed (T. Haugen, Seiler, Sandbakk, & Tønnessen, 2019), enhanced acute or chronic fatigue might be detrimental to improve sprint performance, since they are to jumping ability, since they are a metric to access fatigue levels(Watkins et al., 2017). Also, the difference between an RAST 6x30 m and a true speed training is the interval given between each set, allowing athletes either to recover or not, which is also an indicator has to avoid fatigue accumulation at least during the same session to allow sprint performance adaptations.

According to a systematic review and meta-analysis by Alcaraz (Alcaraz et al., 2018), it seems that heavier loads (>20% BM), hence greater v. loss in comparison to max speed, tend to have a greater transfer to early acceleration , given that is more strength dependent (Alcaraz et al., 2018; Comfort, Bullock, & Pearson, 2012)and the GCT allow to produce more force, this improvements can be seen in Morin (J. B. Morin et al., 2017) were 5-m distance was improved with 80% BM, also in line with Lahti (Lahti et al., 2020) were there was a significant change in GCT for the heavier group (HS60%). Also, in Loturco (Loturco et al., 2013a) were squat 1RM increases there was improvements in the 10 but not 30-m sprint alongside (Fernando Pareja-Blanco et al., 2017) for the 30-m reinforcing the same correlation between strength and early acceleration.. In this same meta (Alcaraz et al., 2018), the authors state that if the load is to heavy (greater v. loss in comparison to maximum velocity), transfer might reduce, due to lack of transfer effect, such has GCT, lack of stretch shortening cycle and H-reflex. Partially in line with Lahti where they were able to improve athletes 10 20 and 30-m sprint times with loads ranging between 94% and 120%, but the lighter group (HS50%) had better improvements than their counterparts in the 10-m. Also, worth mentioning that subjects also performed unresisted sprints, and thus, improvements in the longer distances 20 and 30-m might not be correlated with sled, mainly because of the differences in transferability has mentioned above.

To concluded, interpreters must understand the difference between velocity loss utilized in Grazioli (Grazioli et al., 2020) were G10 and G20 stop when sprint times decrease 10 or 20% respectively, and fatigue was accumulated with a bigger magnitude in the latter group, same for Loturco (Loturco et al., 2013b) during the set of squats, and the velocity loss due increase load such has in Lahti and Morin (Lahti et al., 2020; J.-B. Morin et al., 2017), but no necessarily accumulating the same magnitude of fatigue, related to the inability to contract faster and stronger.

It seems that for acceleration phase, greater velocity loss induced by external load, but not fatigue has positive effect in sprint performance, but the same does probably does not apply to maximum sprint due to the differences in kinetics and kinematics (Alcaraz et al., 2018), but with the available studies in this review, certain conclusion shouldn't be taken due to some studies used a mix of resisted and unresisted sprints.

Finally since 50% velocity loss during a sprint showed better results than 60%, it would be interesting to know until which point increases in velocity loss, stops being resisted sprints to an "general overload exercise".

4.2.3. Jump

Three studies addressed the jumping performance two of them using the squat exercise or a close variation (Loturco et al., 2013b; Fernando Pareja-Blanco et al., 2017) increasing either velocity or intensity and velocity loss during a set respectively, and one using resisted sprints (Grazioli et al., 2020) also using velocity loss cap throw out sets.

Jumping, more specifically, the CMJ, is the result of interaction between muscular proprieties during the concentric and eccentric phases in combination with the elastic elements and neural properties (Laffaye, Wagner, & Tombleson, 2014). Jumping performance is ultimately determine by impulse (Garhammer & Gregor, 1992), but since ones time to produce force is limited due to the nature of task its self, rate o force development (RFD) may be of great importance for jumping performance (Suchomel et al., 2016b). Also in the this same paper by Suchomel and colleagues (Suchomel et al., 2016b), out of 59 studies, 57 (97%) of them reported a positive correlation of greater than or equal to 0.3 (moderate relationship), of which 44 (75%) had a large (0.5) relationship between strength and RFD. That being, Loturco (Loturco et al., 2013a) improvements in Squat 1RM together with conjunction with gradual exposure to different parts of the strength curve (30-60% 1RM) focused on power development, helped improve subjects jumping performance. The same happened in Pareja-Blanco (Fernando Pareja-Blanco et al., 2017) but only to VL15 group. This could be due to less positive increases in Squat 1RM, but also due to more v. loss accumulated throw out every set. Pareja-Blanco (Fernando Pareja-Blanco et al., 2017) reported that the VL30 performed more repetitions a slower compared to the VL15 group. This slower velocity repetitions, caused bigger velocity loss within a set, are related to fatigue which is could negatively affect neural adaptations also related to RFD (F. Pareja-Blanco et al., 2017). In the latter study (F. Pareja-Blanco et al., 2017), with a similar protocol to the one int this review (Fernando Pareja-Blanco et al., 2017), this time with 20% VS 40%, resulted in similar outcomes in regards to of jump performance. Only one study addressed the impact resisted sprint, with loads that varied between 45-65% BW, accumulation 10 or 20% o velocity, with no positive effects, further investigation on different velocity loss to either a unresisted sprint or within session v.loss fatigue related should be employed.

To summarize, it seems that when the focus is to increase strength ta can also benefit jump performance, at least for the squat exercise, low v.loss (<=20%) during a set seems to be more beneficial then higher thresholds (>=30%). Can also be a strategy/tool within the soccer season, where fatigue management is of most importance, due to tight schedules.

With would also be interesting, to use v.loss during a set of squats but also across an entire training session, were athletes would stop performing squats when total velocity loss was for example 10% and 20% like in Grazioli study (Grazioli et al., 2020).

4.2.4. Aerobic

Only Pareja-Blanco (Fernando Pareja-Blanco et al., 2017) addressed the differences in aerobic components when using two different velocity loss, within the same set, with positive outcomes, finding no difference between groups.

There are three key components for endurance performance, Vo2max, lactate threshold and efficiency also known has running economy (Joyner & Coyle, 2008). Strength training is known for its effects on running economy (Blagrove et al., 2018; Guglielmo, Greco, & Denadai, 2009). Since both groups had similar strength increases and the soccer specific training kept equal to both groups at first sight this result should be expected only when accounting for strength gains. On the other hand due to higher v.loss in one of the groups, jumping performance has mentioned above was affected, which could indicate a decrement in the utilization of the stretch shortening cycle, also a contributing factor for running economy (Vikmoen et al., 2017), but no test has really address this situation. On the other hand, the study by Pareja-Blanco implementing the 20 and 40% velocity loss during the squat, also addressed changes in muscle fiber type changes, the results indicated that the VL40% had a shift in fiber type, from the faster (IIX) to slower IIA but more resistant to fatigue. This result might also happen in the reviewed study (Fernando Pareja-Blanco et al., 2017), counterbalancing the possible diminishing utilization of the SSC.

Finally, although both groups improved their aerobic performance, but the VL15 (Fernando Pareja-Blanco et al., 2017) and the VL20 (F. Pareja-Blanco et al., 2017) accumulated considerably less fatigue, with the same outcome. That being is possible that in a long-term or during the specific soccer training, that same fatigue could potentially diminish aerobic improvements due to less ability to perform endurance training.

4.2.5. Kinematic and Spatiotemporal

There was only one study (Lahti et al., 2020) in this review that addressed the impact of different velocity loss during sprint training in kinetic and spatiotemporal variables.

Although there was an immediate impact in both early acceleration and in upright sprint, those mechanics did not transfer to unresisted sprint, neither phase. In contrast, light resisted sprint training has shown a slight increase in trunk lean (Alcaraz et al., 2018; Spinks, Murphy, Spinks, & Lockie, 2007) . In the study by Spinks (Spinks et al., 2007), here thirty, first-level grade, male subjects from various sports (soccer, rugby union and

Australian soccer) endured in either the sprint plus the resisted sprint (RS) (10% v.loss) , sprint training (RS) or the control group (C). Training protocol last for 8 weeks with a frequency of 2 times per week, totalling 16 sessions, where kinematics factors such has trunk lean, where both RS and NRS groups significantly improved trunk lean. However only the RS group had significant difference compared to control group. It is also worth mentioning that in this same study (Spinks et al., 2007) athletes only sprinted 15-m, and that load that induced the 10% velocity loss was calculated by Lockie (Lockie, Murphy, & Spinks, 2003) whereas Lathi (Lahti et al., 2020) used induvial force-velocity profile by Cross (Cross et al., 2017), using distances between 45 and 20-m. This difference in load selection test could mean that the "lighter" load in Spinks (Spinks et al., 2007) could actually be different were if they were using induvial load-velocity profile has in cross (Cross et al., 2017).

That being, it would be recommend that a standardized test, preferably the individual load-velocity profile, so that precise velocity loss is induced, and study can be better compared.

Finally, it seems that heavy resisted sprint training does not affect unresisted sprint kinematics in both acceleration and and upright sprint phases. Longer term usage of this methods of training would also be recommended.

4.3.Study limitations

Due to the limited amount of research using the same loading protocols (%1RM or VBT), training protocols and different ways to impose velocity loss (fatigue, external load) or lack of research in heavy resisted sprints, more research should be done using standardized methods such individual load-velocity profile, velocity targets (ex: Squat 3x3 at 0,4-0,5 ms) for example.

4.4.Future research and practical applications

- It seems that for increases in strength low v. loss (<20%) during the squat exercises seems to not differ in terms of outcomes.

- Although higher loss has an increase potential for hypertrophy (F. Pareja-Blanco et al., 2017), that also comes it an increase fatigue and less positive or even negative effects in jumping performance (F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco et al., 2017).

-Therefore, the usage of velocity loss impose by fatigue accumulation should be both monitored and periodized during every training session. That being, monitor velocity to understand increases in a given exercise strength or, on the other hand, adjust load in time according to athlete's readiness. Periodize v.loss according calendar, for example higher v.loss during the off season and lower during the season, or even body parts, allowing higher velocity thresholds for upper body in soccer players if hypertrophy is desired, since too high of these thresholds for the lower body might impose to much fatigue when combined with specific soccer training.

-Regarding specific sprint training with overload (sled) it seems that too much of velocity loss through the training session, overall fatigue accumulated during every set, seems to have a decremental effect in sprint performance, has seen in Grazioli (Grazioli et al., 2020) here G10 had better improvements in the 10 and 20-m sprint compared to the G20, that had more sprints completed.

- Erasing the question, if v.loss imposed by overall accumulated fatigue in every set during resisted sprint training, affects sprint performance. Does also more traditional strength training such has squats with an high v.loss during a set (30%+), leading also to an overall accumulated fatigue in every set, has a decrement in resisted sprint training done with low velocity loss by accumulated fatigue has in the g10, if performed in the same day or training session?

-If so matching traditional strength training speeds and v.loss due to fatigue for a given exercise should be paired with speed and agility based training and/or soccer specific?

-It seems that, higher v.loss due to external low during resisted sprints has a the ability to improve sprint performance.

-External load should be done according to time decreases compared to unresisted sprints instead of using %BM, hence, v. loss compared to maximum velocity.

-To prescribe load that induces the v.loss compared to maximum velocity, practitioners should use an individual load-velocity profile, if possible.

-If not possible, a recommendation is to choose a fixed load (%BM) and see if improvements in resisted sprints matching improvements in unresisted sprints.

-The same can be done for other exercises, for example squat jump at a given fixed speed and CMJ height.

-Heavier loads up to a certain point (60% v.loss relative to maximum speed according to Lahti (Lahti et al., 2020)) can also improve sprint performance with effects in kinematic variables.

- 50% v.loss compared to maximum speed during sprints has a clear superior effect than 60%.

5. Conclusions

With increases in VBT technology availability and reliability, practitioners should consider the usage of this devices to accurately prescribe training according to the one's readiness, objective and calendar. Implementing VBT metrics like v.loss due to fatigue accumulation to better manage fatigue, manly during the soccer season should be implemented.

Other information

Registration and protocol

The protocol was published in INPLASY (International Platform of Registered Systematic Review and Meta-analysis Protocols) with the identification number of INPLASY202160036 and DOI 10.37766/inplasy2021.6.0036.

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Competing interests

The authors declare no conflicts of interest.

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Table 1. Inclusion and exclusion criteria

	Inclusion criteria	**Exclusion criteria**
Population	Healthy soccer players of any age, sex or competitive level	Sports other than soccer; players with injuries, illness or disabilities
Intervention	Intervention/exposure using VBT.	Non-VBT based training.
Comparator	Controls performing field-based soccer training, with or without additional non-VBT physical training. Alternatively, controls performing VBT with different velocity losses.	No control groups.
Outcome	At least one pre-post acute and/or a chronic outcome (acute response: immediate response of a physical or physiological variable in response to the exercise; chronic response: adaptations promoted by the training intervention, consisting in permanent changes in physical or physiological variables) related to physiological (e.g., heart rate responses, blood lactate concentrations, oxygen uptake, rate of perceived exertion) and physical (e.g., strength and power, speed, change-of-direction, aerobic capacity) measures	No pre-post data related to acute and/or chronic physiological and physical measures
Study design	Multi-arm designs (randomized or non-randomized).	Descriptive studies or observational analytic.

Additional criteria	Only original and full-text studies written in English, Portuguese, Spanish, Italian and French.	i

Table 2. Characteristics of the included studies

SDes	N	Age (y)	Sex/Competitive level	Design	Outcomes	Tests used in the original studies	ext test
Rand.	32	VEL = 19.18+-0.72 years INT= 19.11 +- 0,7 years	Masculine Brazilian elite soccer players	Soccer players were split in two groups (IN and VEL). Training protocol divided by common 3week strength program followed by a 3-week power-oriented program, were, VEL increased velocity INT decreased	Strength and power, jump and sprint performance	- Squat 1RM - Mean Power Squat - Mean Power Jump Squat - Squat Jump - Countermovement jump - 10-m Sprint - 30-m Sprint	- - - - - -
Rand.	17	25.8 +-4.3 years	Male Brazilian professional soccer players	Soccer players were split in two groups according to their velocity loss during the sled resisted sprints (10% velocity loss	Isokinetic, jump and sprint performance	- 20-m Sprint - Squat Jump - Countermovement Jump - Maximal isometric torque - Maximal isokinetic torque - Isometric rate of torque development	- - - -

				G10 and 20% velocity loss G20).		
Rand.	16	23.8 +-3.4	Highly trained male soccer players	The players were split in two groups VL15 and VL30, where they would stop the squat set when a 15% and 30%, respectively, of velocity was loss.	Strength and power, sprint and jump performance, aerobic	- 30-m Sprint - Countermovement Jump - Isoinertial squat loading - Yo-Yo Intermittent Recovery Test Level 1
Rand.	16	26.3 +- 4.0	Amateur male soccer players	Players were divided in two groups, control and VHS. Control group performed only unresisted sprints whereas VHS performed a mix of resisted and unresisted sprints.	Sprint performance	- 30-m Sprint - Force-velocity profile
NRand.	32	24.1+-5.1	Premier Male Finland soccer division	One control group and two intervention	Sprint performance	- 30-m Sprint - Force-velocity profile - Spatiotemporal and Kinematics

					groups HS50% and HS60%. Intervention groups endure in a resisted sled sprints where the goal was to reduce sprint time by 50% (HS50%) and 60% (HS60%).			

SDes: study design; Rand.: randomized; NRand.: non-randomized

Table 3. Characteristics of the training protocols using velocity-based training.

Study	Duration (w)	d/w	Total sessions (VBT interventions) (n)	Exercises included in the intervention	Sets x Rep	Intensity	Recovery (min)
(Lo turco et al., 2013b)	6 weeks	2x /week	0 *	Back Squat Jump Squat	Strength oriented 4x8 Power oriented 4 x 4-6	Strength-oriented 50-80% 1RM Power-oriented 30-60% 1RM	2'
(Grazioli et al., 2020)	11 weeks	1x /week	10	Resisted Sprints	Total reps G10- 33.75+- 9.22 Total Reps G20- 48.76+- 7.50	45-65% Body weight	ND
(Fernando Pareja-Blanco et al., 2017)	6 weeks	3x /week	18	Back Squat	According to velocity loss.	50-70% 1RM Or 1.13- 0,82 m/s	4'

(J.-B. Morin et al., 2017)	8 weeks	2x /week	16	Resisted and unresisted Sprints	2x 2 x 5	0 or 80% Body weight	2' between reps 5' between blocks
+(Lahti et al., 2020)	9 weeks	Almost 2x/week	ND	Resisted and unresisted sprints	6-8 x 1	Load was chosen to elicit 50 or 60% velocity loss	3'

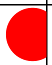
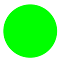
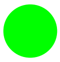
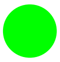
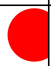
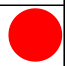
w: weeks; d/w: days per week; VBT: velocity-based training; Rep: repetitions; min: minutes; ND: not defined. *%1RM based to prescribe load. ** Half of the training program performed 2 unresisted sprints, the other half only performed one.

Table 4. Assessment of the risk randomized studies included with RoB 2

Study	D1	D2		D4	D5	Overall
(Loturco et al., 2013b)	🟡	🟢	🟢	🟢	🟡	🟡
(Grazioli et al., 2020)	🟢	🟢	🟢	🟢	🟡	🟡
(Fernando Pareja-Blanco et al., 2017)	🟡	🟢	🟢	🟢	🟡	🟡
(J.-B. Morin et al., 2017)	🟡	🔴	🔴	🟡	🟡	🔴

D1: randomization process; D2: deviations from intended interventions (ITT); D3: missing outcome data; D4: measurement of the outcome; D5: selection of the reported result; Green- low risk; Yellow: some concerns; red: high risk of bias

Table 5. Assessment of risk of bias in non-randomized trails included with ROBINS-I

Study	D1	D2	D3	D4	D5	D6	D7	Overall
(Lahti et al., 2020)								

D1: reaching risk of bias judgements for bias due to confounding; D2: reaching risk of bias judgments in selection of participants into the study; D3: reaching risk of bias judgments for bias in classification of interventions; D4: reaching risk of bias judgments for bias due to deviations from intended interventions; D5: reaching risk of bias judgements for bias due to missing data; D6: reaching risk of bias judgements for bias in measurement of outcomes; D7: reaching risk of bias judgments for bias in selection of the reported result; Green: low risk; Yellow: moderate/serious risk; Red: critical risk

Table 6. Qualitative synthesis and summary measures considering the chronic effects of VBT methods.

Study	Strength & Power	Sprint	Jump	Aerobic	Sprint Kinematics & Spatiotemporal
(Loturco et al., 2013b)	Significant changes pre-to-posttest Squat 1RM (kg) (VEL: 19,8%; INT:22.1%). No significant differences in changes between groups Squat 1RM (kg). Significant changes pre-to-posttest Back Squat mean power (W) (VEL: 18.5%; INT: 20.4%) No significant differences in changes between groups Squat Mean Power (W).	Significant changes pre-to-posttest in 10-m sprint time (s) (VEL: -4.3%; INT: -1.6%). No significant differences in changes between groups 10-m sprint times No significant changes pre-to-posttest in 30-m sprint time (s) (VEL: -0.8%; INT: -0.1%).	Significant changes pre-to-posttest Jump Squat height (cm) (VEL: 7.1%; INT: 4.5%) and CMJ height (cm) (VEL: 6.7%; INT: 6.9%). No significant differences in changes between groups in Jump Squat height (cm) and CMJ height (cm).		

	Significant changes pre-to-posttest Squat Jump mean propulsive power (W) (VEL: 29.1%; INT: 31.0%). No significant differences in changes between groups Squat Jump mean propulsive power (W).				
(Grazioli et al., 2020)	Significant decreases in Quads Iso Peak Torque (N) in G20 (-14.4+-12.5%) and G10 (-1.7 +-6.7%) no difference between groups. No additional significant effects. No additional significant effects.	Greater improvement G10 in 10-m sprint time (s) (-5.5+- 3.3% vs -1.74+-5.94%) 20-m sprint time (s) (-2.5+- 2.1% vs 1.4 +- 3.76) than G20. No additional significant effects.	Significant decreases in CMJ height (cm) G20 (-7.1+-4.7%) and G10 (-1.7 +-6.7%). No additional significant effects.		
(Fernando Pareja-Blanco et al., 2017)	VL15 significant improvement Squat 1RM (P<0.01).	No significant differences between pre-to-post-test in both groups.	VL15 significant greater improvement CMJ height (cm) (P<0.05).	Significant difference pre-to-post-test in YYIRT (m) in both groups (P<0.01).	

	VL15 likely positive effect Squat 1RM (kg) (101.3+-18.1 to 110.3+-14) vs VL30 possibly a positive effect Squat 1RM (kg) (100.2+-20.3 to 106.5+-28.5) VL15 possibly positive effect AMPV (m/s) (1.19+-0.12 to 1.23+-0.09) vs VL30 unclear effect AMPV (ms) (1.16+-0.11 to 1.18+-0.13)		VL30 no significant CMJ improvements. Possibly negative effects CMJ performance VL30 groups	No significant difference in changes between groups.	
(J.-B. Morin et al., 2017)	VHS F0 (N/kg) pre-to posttest moderate effect (ES= 0.080+-0.61). VHS RFmax (%) pre-to-posttest moderate effect (ES= 0.85+-0.66)	5-m sprint (s) VHS moderate positive effect (ES=-0.68 +-0.59) vs CON small positive effect (ES=-0.23+-0.27). 20-m sprint (s) VHS small positive effect (ES=-0.40 +-0,44) vs CON trivial			

	CON F0(N/kg) and RFmax (%) pre-to-posttest unclear effect (ES= 0,20+-0.53; ES=-0.11+-0,54). VHS v0 (m/s) trivial effect (ES=-0.16+-0.30). VHS DRF ability moderate negative effect (ES=-0.61+-0.52).	positive effect (ES=-0.12+-0.13).			
(Lahti et al., 2020)	Significant F0 (N/kg) improvements HS60% (p=0.02) and HS50% (p=0.02). Significant Mean RFmax (%) improvements HS60% p=0.013; ES=0.80) and HS50% (p<0.001 ES=1.14). Significant Maximum Power (W/kg) improvements	Significant improvements 10-m sprint (s) HS60% (p=0.001; d=-0.96) and HS50% (p<0.001; d=-1.25). Significant improvements 20-m sprint (s) HS60% (p=0.008; d=-0.77) and HS50% (p<0.001; d=-1.15). Significant improvements 30-m sprint (s) HS60% (p=0.02; d=-0.62)			*Immediate significant change HS60% in contact time (s) (p=0.002) step rate (p=0.004) and step length (p=0.008). *Immediate significant decrease CM touchdown distance (m/bodylenght) HS60% (p=0.003) and HS50% (p=0.003). Significant decrease CM angle at

	HS60% p=0.011) and HS50% (p<0.001). Significant improvements in velocity (m/s) in HS50% (p=0.04; 3.08% change). Velocity (m/s) HS60% (p=1.00; 1.79% change). Pmax (W/kg) improved significantly more in HS50% vs Control Group.	and HS50% (p<0.001; d=-1.18). 10-m sprints (s) improved significantly more in HS50% vs Control Group.			touchdown (º) HS60% (p=0.005) and HS50% (p=0.005). Pre-to-posttest significant decrease in contralateral hip angle at touchdown (º) HS60% (-4,01%; p=0.004) CON (-3.13%; p=0.006).

*Acute responses

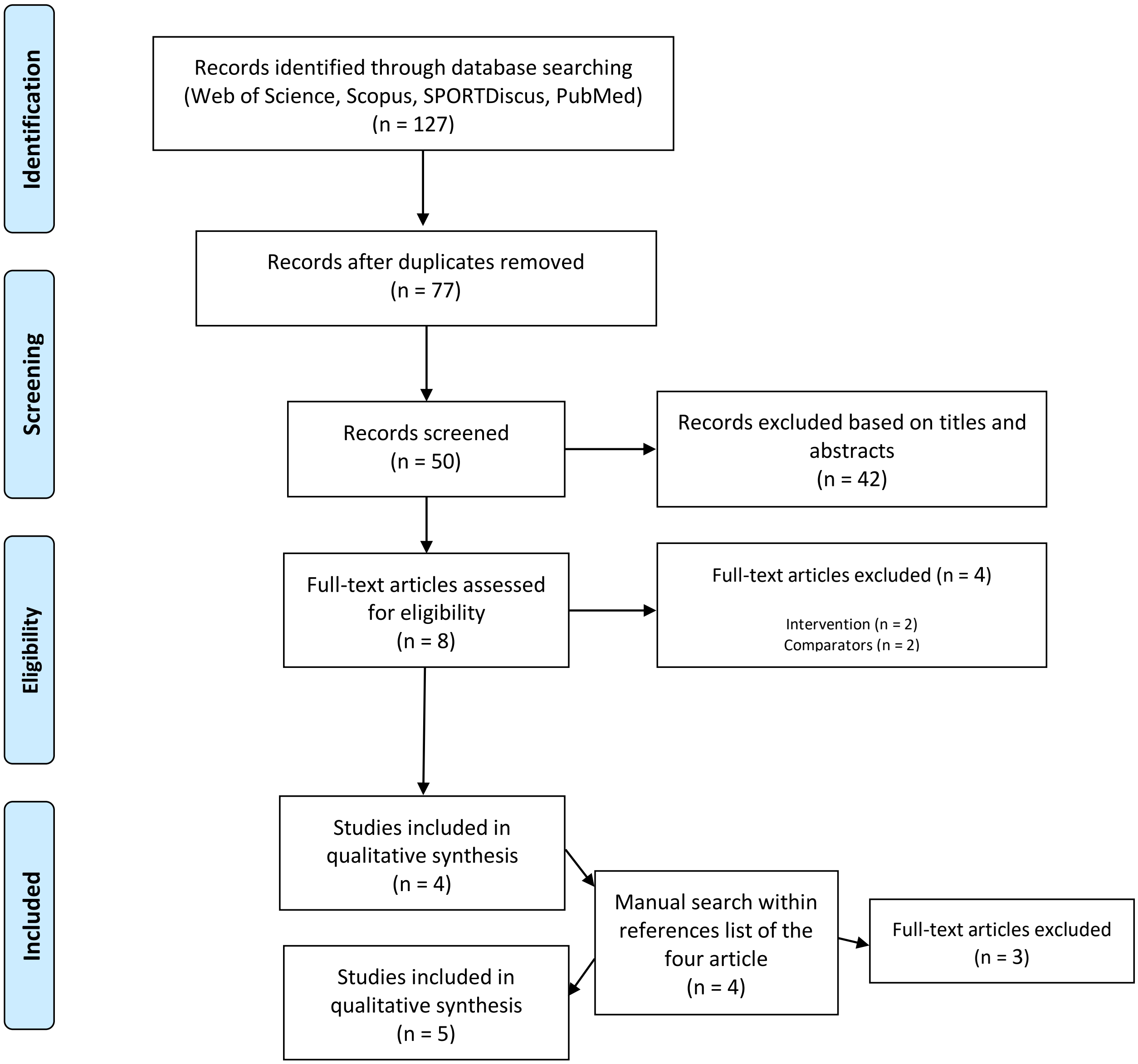


Figure 1. PRISMA flow diagram highlighting the selection process for the studies included in the current systematic review.

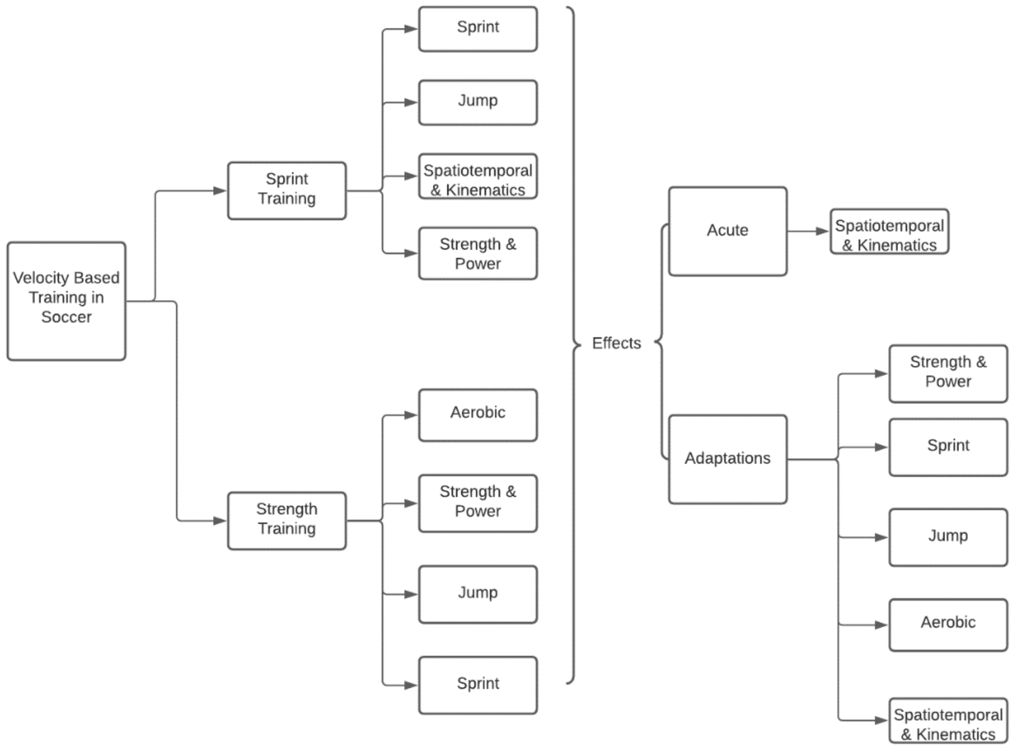


Figure 2. Concept map.

CHAPTER 3- DISCUSSION

In an ideal scenario, strength and power training would be separated at least 3-6 hours apart from endurance training, in order to minimize the training induced overall fatigue and maximize concurrent training effect (Methenitis, 2018), but that's not always possible and also avoiding training in a glycogen depleted state since it can potentially impact performance in both modalities (Enright et al., 2017b; Trexler, 2021) augmenting even more the molecular mechanism associated with interference effect ("Low Energy Level" chapter).

Goal of this discussion is therefore, in a real-world scenario, where strength and power training will be performed intra-session, at least where the pre-requisite of 3-6 hours might not be always possible, how can coaches and staff implement the best strategies, using VBT for their strength and power training alongside HIIT in order to maximize training adaptations.

It is know that interference effect affects strength and power and hypertrophy in different magnitudes, being power and or high velocity contraction the most harmed (Schumann & Rønnestad, 2019; J. M. Wilson, Marin, et al., 2012a). Although either AMPK, p53 activity, ER stress or SITR can block muscle protein synthesis (Baar, 2014; Ghosh et al., 2010; Methenitis, 2018; Nader, 2006; Schumann & Rønnestad, 2019), and for p53 activity might be independent endurance training regime (cont. vs HIIT) for equalized volume (Bartlett et al., 2013), this mechanisms can diminished if some nutritional strategies, such has providing carbohydrates and protein between both modalities (Perez-Schindler et al., 2015), possibly diminishing the activation of all the above mechanisms (Baar, 2014; Bartlett et al., 2013; McBride, Ghilagaber, Nikolaev, & Hardie, 2009; Zhang & Kaufman, 2006). Also, the study from (Jonathan D. et al., 2012) was to an equalized volume during a 3 minute at 90% Vo2max followed by a 3 minute active rest at 50%Vo2max for six rounds, totalling 36 minutes of activity plus 14 minutes for warm up and cooldown. But would the results be the same if higher intensities a thus lower volumes were utilized (ie. six rounds of 1 minute at 100% Vo2max and 1-minute active rest at 50%Vo2max) or even utilising passive rest to control even more the energy expenditure. And instead of using total time to match training modalities, rather utilizing T@Vo2max for both protocols, would probably lead to less time need for HIIT style training and possibly diminished AMPK and p53 activity since due to lower energy demands (Kirsten A. et al., 2008; Romeu B. et al., 2017).

Has for strength, it depends on both muscle hypertrophy and neural adaptations (Schumann & Rønnestad, 2019), so it may be difficult to understand to which level interference occurs on strength. In a study by (Enright et al., 2015) athletes elite premier league youth soccer players(17.6+- 1.6 years) were expose to either strength followed by endurance or endurance by strength. Athletes increased 1-RM back squat that didn't translate to the peak force generated during the isometric test, thus the improvements might be due to technical proficiency and not neural improvements. Although they were youth, they already possessed 2 years of prior strength training with good baseline levels of strength (almost 2 times BW Squat) which could give less room to improvements. Unfortunately, the isometric test wasn't carried doing a isometric-mid tight pull with no strength standards to compare to, but it seems that for the neural component of the knee extensor strength wasn't compromised, even they aren't at a beginner level. In a study by Häkkinen (Häkkinen et al., 2003a) were 32 recreationally active men (endurance activities with no resistance training background) were divided in groups were they either strength training or combined strength with endurance (RT programme also had explosive type movements included), for 21-weeks. The main outcomes in this study were that muscle hypertrophy and strength gains in the concurrent training group did not differ from the strength group only. In fact this goes in line with the work of Coffey and colleagues (Coffey & Hawley, 2017) that showed that concurrent training modality does not affect untrained subject and it is more of a general stimulus, and even bike alone can cause hypertrophy and has training level increases so does the interference effect, in which is possibly the category that the subjects on Häkkinen (Häkkinen et al., 2003c) were also endurance training was performed on a bike, and there were no statistical difference between groups in muscle fiber cross-sectional area increases with no significant difference in fiber type shiffting. An also interesting result form this same study, is the fact that RFD only increase in the strenght group but not in the concurrent group. There was also a tendency for a shit from type IIb muscle fibers to type I with no, significant difference between groups.

Also raising the question, since fiber type shiffting was not not affeted, even when manly low to moderate cardio was utilized, possibly not stimulating type II muscle fibers to the same degree has HIIT training (Altenburg et al., 2007; Gollnick et al., 1974), but RFD was? If so, can the interference effect occur mutch sonner regarding neural adaptations? Which is an interesting fact since, strenght and hypertrophy might not be affect at a biggener level but it seems the neural adpatitions regarding strenght and power were, but further stuides should be carryed regarding this topic on untrained subjects. Futhermore it is also suggested by Dudley and Djamil (Dudley & Djamil, 1985; Schumann & Rønnestad, 2019; J. M. Wilson, Marin, et al., 2012a) that force at high-velocties is more affected that force at low velocities. This is also visible in the acute studies from the systematic review regarding concurrent training above in this thesis, were the were imparements in jumping ability.

To this point it seems that the higher the contraction velocity stimulus and thus desired adaptaions, the more interference occurs either to fiber type shifting or neural adaptations (Coffey & Hawley, 2017; Dudley & Djamil, 1985; Häkkinen et al., 2003a; Schumann & Rønnestad, 2019; J. M. Wilson, Marin, et al., 2012a).

When it comes to resistance traning it seems that higher v.loss (due to fatigue) (>40%) also has a negative impact on fiber type distribition, resulting in a decrease in percentage in myosin heavy chain type IIx compered to low velocity (F. Pareja-Blanco et al., 2017). Possibly having an impact on CMJ performance, since lower v.loss group (20% v.loss) had an increase of 9.5% with no changes in the higher v.loss group (40% v.loss). This same line of researchers (Fernando Pareja-Blanco, Sánchez-Medina, Suárez-Arrones, & González-Badillo, 2011) had the same results regarding CMJ performance, again favoring the lower v.loss group (15%v.loss vs 30% v.loss) along with endurance. Has for strenght it seems that is either indiferent or in favor of low v.loss groups (F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco et al., 2011). Has for sprints neither had a significant impact, lickly due to low degree of transference (Harris et al., 2000; Young, 2006). When aplying a more transferabel exercise to sprints/max velocity, such has resisted sprints, it also seems that v.loss (due to fatigue) has a detrimental effect (Grazioli et al., 2020), with a much lower tolarance to v.loss, since 20% already had lesser of an adaptation to sprint. When compared to a more traditional strength and hyperthrohy (lower overall velocities) even 20% v.loss did not significantly affect fiber type nor neural adaptations (better avg. mean propolsive velocity at all loads until 1 m/s starting at 20kg and CMJ) (F. Pareja-Blanco et al., 2017) but when the nature of the exercise is more power/maximum speed based, the lower v.loss treshold can possibly be sustained in order to impair adapatation. Making the case that when implementing sprint/max velocity focus session, fatigue (high v.loss tresholds) accumulation might be detrimental either from possibly purely neural factors since the 20% v.loss in (F. Pareja-Blanco et al., 2017) did not negativly affect fiber type shiffting towards type I.

To summarize this part of the discussion, it is possible that higher v.loss (>20%) might not favor the more explosive fiber types and consequently accumulating more fatigue accumulation either due to neural or pehriphral factors (Galiano et al., 2020; F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco et al., 2011; Sanchez-Medina & González-Suárez, 2009; J. Weakley et al., 2021; J. Weakley, McLaren, et al., 2020).

There are several variables (9) that practitioners can manipulate HIIT training, being the duration of work and relief the key influencing factors, followed by the number of intervals, sets, between intervals recover duration and intensity, which, all together will fundamentally determine the total work done (Buchheit & Laursen, 2013a).

In order to control the anaerobic glycolytic contribution, and therefore the metabolite accumulation, increasing work intensity for the same work/relief ratio during long intervals, will increase blood lactate accumulation or if for the same intensity interval duration is extended while maintaining the same work/relief (Buchheit & Laursen, 2013b; Seiler & Hetlelid, 2005; Smith, Coombes, & Geraghty D.P., 2003; Stepto, Martin, D, Fallon, & J.A, 2001) (Buchheit & Laursen, 2013b). Another example is for the same work intensity and duration diminishing the work/relief ratio also produces increases in blood lactate levels (Buchheit & Laursen, 2013b).

Has for short intervals, it seems that athletes can work at higher intensity with a relative lower blood lactate level (Astrand, Astrand, Christensen, & Hedman, 1960a, 1960b; Christensen, Hedman, & Saltin, 1960) , where logically the same rules are applied has in the long bouts (Buchheit & Laursen, 2013b).

Overall, the more work is done in the least amount of time, independent of which variable is manipulated, probably enhance blood lactate levels, knowing that is possible to work at higher intensities in shorter bouts, but if volume is too high will also probably produce too much of a fatigue throw a combination of neuromuscular load and musculoskeletal strain.

How to combine both HIIT (RSS, SIT, all-out efforts, short and long intervals) and resistance training (hypertrophy, strength, power, and speed) will be the remaining focus os this discussion, combining the above information to impose better practices during concurrent training methods.

Since hypertrophy is where seems to be least interference effect occurs (Schumann & Rønnestad, 2019; J. M. Wilson, Marin, et al., 2012a),possibly with diminish interfence when done either in a ergometer (Gergley, 2009; J. M. Wilson, Marin, et al., 2012b) or if not done without the presence of carbohydrates / not in a lipid exposure state ("Low Energy" chapter). This type of resistance training is associated with higher v.loss, thus more fatiguing (Galiano et al., 2020; F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco et al., 2017; Sanchez-Medina & González-Suárez, 2009; J. Weakley et al., 2021; J. Weakley, McLaren, et al., 2020) sessions. Combine the more fatiguing HIIT by volume (long- intervals ie. 5x > 2-3min [85-100% Vo2max]/ 2-3min [0%]) or intensity (all out efforts or SIT (longer efforts at high intensity), RSS with low work/ relief ratio or SIT (Wingate) (Buchheit & Laursen, 2013a, 2013b) to holistically allocate stress during the week, and possibly the type of session that have a higher potential to cause fiber type shifting and/or neural fatigue (Buchheit & Laursen, 2013a, 2013b). There is data regarding how HIIT induced fatigue affects either central or neural fatigue (Lattier, Millet, Martin, & Martin, 2004; Perrey, Racinais, Saimouaa, & Girard, 2010; Skof & Strojnik, 2006; Vuorimaa, Virlander, Kurkilahti, Vasankari, & Häkkinen, 2006). Very short to short (<20s up to <1min respectively) and/or non-maximal sprints (~< 120%Vo2max) tends to be manly from a peripheral origin (Girard, Bishop, & Racinais, 2013; Lattier et al., 2004; Mendez-Villanueva, Edge, Suriano, Hamer, & Bishop, 2012; Perrey et al., 2010) while during repeated long sprins (≥ 30s/ wingate) or all out efforts tend to be both neural and peripheral (Fernandez-del-Olmo et al., 2013). If applying RSS or SIT type of cardio, in a running modality, might expose the lower body muscles at high velocity contractions with a type of training that already cause possibly a considerably high muscle damage (Schoenfeld, 2012), thus possibly exposing players to a higher degree of injury risk, manly in the hamstrings (Edouard et al., 2017).

Has for strength, it seems that training is generally performed in a lower rep/high load scheme and lower absolute velocity (near MVT) and velocity thresholds leading to less overall volume and fatigue. (Banyard et al., 2017; Galiano et al., 2020; F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco et al., 2011; Sanchez-Medina & González-Suárez, 2009; J. Weakley et al., 2021) a possibly less muscle damage due to less volume being performed. Nevertheless, the fact that absolute velocities are much lower compared to the ones performed in power and speed training (Banyard et al., 2017; J. Weakley et al., 2021). Along with the fact that it seems to be the type of adaptations less prone to interference next to hypertrophy. Therefore, might me suited for longer interval type training, but with a higher intensity/lower volume than hypertrophy. Diminishing work intervals from >2-3min to ~1min for example, in contrast with intensity which could go up, to control for total time performed in endurance or decrease in work/relief ratio in which will cause the session to be more metabolic demanding but not neural. SIT might be to taxing for the for the nervous system, since in general is performed between 160-180%Vo2max (figure 4) (Buchheit & Laursen, 2013a, 2013b) for longer periods of time (>20s) , and thus interfere with strength adaptations. Has RSS being short burst of 3-7s sprints, and similar in terms of intensity, the work duration is much lower not being has demanding has SIT during work. In above mentioned study by Buccheit (Buchheit & Omeyer, 2002), there was a decrement in CMJ performance for both RSS (12x5 s [sprints]/25 s[0]) and short HIT (30 s [93 %VIFT]/30 s [0]) but not for the other short HIT (10 s [110 %VIFT]/20 s [0]). Now whether this translates to maximal force production adaptations is unknown but its surely and indicator for speed and power training, which are likely prone a higher to interference than has it has been discussed along this thesis. Also the fact that absolute velocities are much lower compared to the ones performed in power and speed training (Banyard et al., 2017; J. Weakley et al., 2021), thus training closer to failure/ near MVT, can be a proxy for hight training demands, which can be paired with the other more fatiguing/demanding HIIT session, so there again allocate fatigue along the week an provide an all-round endurance for the athletes, leaving the less neural/metabolic demanding with less interference for the speed and power work.

Has for speed and power which are performed at moderate to high absolute velocity preferably with low v.loss (<20%) (Banyard et al., 2017; J. J. González-Badillo & Sánchez-Medina, 2010; Mann et al., 2015; F. Pareja-Blanco et al., 2017; Fernando Pareja-Blanco et al., 2011; Sanchez-Medina & González-Suárez, 2009; J. Weakley et al., 2021) , along with the short-intervals mentioned above, with a intensity between >80-85 up 120% Vo2max speed (figure 4) might to be the best practice, because it either stimulates type II fibers (Altenburg et al., 2007; Gollnick et al., 1974) without over taxing the central nervous system but also less metabolic stress when compared to longer intervals, utilising a work/relief ratio (1:2, 1:3, etc) that also allows lactate levels to remain low (Buchheit & Laursen, 2013b). This way practitioners can still provide a strong anaerobic stimulus mitigating the fatigue build up, due to either metabolite accumulation or neural fatigue or a combination of both, with effort duration like the ones found in sprints (5-15s). It might also be important to think in terms at what percentage of maximum speed are exposing the athlete to, and if the %Vo2max prescribed is that close to the ones ability to express speed. For example, if two athletes A and B have the same Vo2max but at A has a top speed of 29 km/ and the other has 35 km/h. Implementing a a running intensity of 130% Vo2max (figure 4) might impose to much of neuromuscular fatigue to athlete A but not to B because he is still working at lower percentage of maximum speed. Also, if intensity is increase probably rest time should also increase in order to control for neural fatigue.

CHAPTER 4- CONCLUSIONS

To give a more well-rounded strength and conditioning training, were all the checkboxes are accomplished regarding strength power and speed along with various metabolic demands form endurance training, coaches need to better combine HIIT training according to the desire outcome regarding the RT.

Velocity targets the focus on the desired adaptation like the ones in figure 1, should be utilized along with v.loss or set cap in order to control for unnecessary fatigue has it has no difference in strength outcomes when it comes to high vs low velocity loss (40 and 30% vs 20 an 10%). Or even to the detrimental effect on power and speed training.

Also, combining the above information regarding VBT and HIIT training to mitigate concurrent training effect, it also the additional advantage, with this objective data practitioner can holistically allocate fatigue throughout the microcycle and along the entire season and offseason.

Finally, from a personal experience, VBT should be used alongside RPE. They are not mutually exclusive, manly and when it comes to low-velocities there is less margin for v.loss, and although the velocity of last repetition might indicate there were more on the tank, we cannot guess the drop that could occur if one more would be performed.

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