



Escola Superior de Desporto e Lazer

**Strength and Conditioning Training in Handball: A Review of Physical Fitness
Adaptations Promoted by Plyometric Training and High-Intensity Interval Training**

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Master's degree in Sports Training

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RESUMO

A presente dissertação de mestrado em Treino Desportivo apresenta dois estudos de revisão focados nos efeitos do treino pliométrico e do treino intervalado de alta intensidade em diferentes parâmetros da aptidão física em atletas de andebol. **Objetivos:** o principal objetivo da dissertação centrou-se em sumariar as principais evidências sobre o impacto do treino pliométrico e o treino intervalado de alta intensidade na aptidão física de atletas de andebol. No primeiro estudo elaborou-se uma revisão sistemática de escopo para descrever os métodos e efeitos do treino pliométrico em diferentes parâmetros da aptidão física de atletas de andebol, e no segundo estudo foi elaborada uma revisão sistemática para avaliar os métodos e efeitos do treino intervalado de alta intensidade na resistência cardiorrespiratória de atletas de andebol. **Métodos:** ambos os estudos seguiram as orientações PRISMA 2020 e a abordagem PICOS, sendo ambos registados na plataforma OSF. Ambas as revisões incluíram apenas artigos completos que foram pesquisados nas plataformas PubMed, Scopus, SPORTDiscus e Web of Science. Ambos as revisões utilizaram instrumentos de avaliação do risco de viés e extraíram dados associados às características dos participantes, dos programas de intervenção e as variáveis de aptidão física recolhidas antes e depois dos programas de intervenção. **Resultados:** o primeiro estudo incluiu 35 artigos, de um total inicial de 3195, e o segundo estudo incluiu 17 artigos, de um total inicial de 434. A primeira revisão mostrou uma variação considerável de resultados, mas a maioria dos estudos presentes na revisão mostrou um impacto positivo do treino pliométrico na capacidade de salto, velocidade e mudança de direção. Na segunda revisão houve uma variação considerável de resultados nos diferentes estudos, mas a maioria demonstrou um impacto positivo do treino intervalado de alta intensidade nas diferentes variáveis de resistência cardiorrespiratória. **Conclusão:** o treino pliométrico e o treino intervalado de alta intensidade são, globalmente, estratégias metodológicas com benefícios na melhoria da aptidão física de andebolistas.

ABSTRACT

*The present master's dissertation in Sports Training presents two review studies that focus on the methodology and effects of plyometric and high-intensity interval training in different physical performance variables of handball athletes. **Objectives:** the main goal of this thesis was to summarize the main evidences regarding the impact of plyometrics and high-intensity interval training in the physical performance of handball athletes. In the first study a systematic scoping review was made to describe the methods and effects of plyometric training in various physical performance variables, and in the second study a systematic review was made to evaluate the methods and effects of high intensity interval training on cardiorespiratory endurance performance. **Methods:** both studies followed the PRISMA 2020 guidelines and the PICOS approach, and were registered at OSF. Both reviews only included full text-articles that were searched on PubMed, Scopus, SPORTDiscus, and Web of Science platforms. Both reviews utilized risk of bias assessment instruments and extracted data associated to the characteristics of the participants, the intervention programs and physical fitness variables obtained before and after the intervention programs. **Results:** the first study included 35 articles, from a total initial amount of 3195, and the second study included 17 articles, from a total initial amount of 434. In the first review there was a considerable variation in outcomes across the included studies, but most of them demonstrated a positive impact of plyometric training on improving jumping ability, sprinting speed, change of direction. In the second review there was a considerable variation in outcomes across the included studies, but most of them demonstrated a positive impact of high-intensity interval training on improving different variables of cardiorespiratory endurance. **Conclusion:** plyometric and high-intensity interval training are, generally, beneficial methodological strategies to improve physical fitness in handball players.*

LIST OF ABBREVIATIONS

1RM – 1 repetition maximum

30-15IFT – 30-15 intermittent fitness test

CMJ – countermovement jump

COD – change of direction

DJ – drop jump

FFM – fat free mass

HIIT – high-intensity interval training

MAS – maximum aerobic speed

PA - Pennsylvania

PICOS - population, intervention, comparator, outcome, study design

PRISMA - Preferred Reporting Items for Systematic reviews and Meta-Analyses

PT – plyometric training

RFD – rate of force development

RM – repetition maximum

RSA – repeated sprint ability

RSI – reactive strength index

RST – repeated sprint training

S&C – strength and conditioning

SAID – specific adaptations to imposed demands

SIT – sprint interval training

SJ – squat jump

SSC – stretch-shortening cycle

SSGs – small-sided games

USA – United States of America

VIFT – Velocity at the 30-15 intermittent fitness test

VO₂max – maximal oxygen uptake

vVo₂max – velocity at maximal oxygen uptake

WA - Washington

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CHAPTER 1 - INTRODUCTION, STATEMENT OF CONTRIBUTION AND RESEARCH OBJECTIVES

1.1. INTRODUCTION

Understanding the physical demands during handball official competition is essential to achieve the highest performance in the sport (García-Sánchez et al., 2023). Given that handball is characterized by fast-paced offensive and defensive actions, as well as frequent body contact, players must be physically prepared to produce the required actions to beat their opponents, while maintaining speed and intensity throughout a match. Those actions include different general movements like walking, running, jumping and changing directions, as well as handball-specific actions like passing, catching, throwing and blocking (García-Sánchez et al., 2023).

Regarding energy systems, handball is a game with intermittent actions that primarily targets the aerobic metabolism, interspersed by high-intensity actions that greatly tax anaerobic metabolism (Povoas et al., 2012), which requires athletes to be well prepared both aerobically and anaerobically.

It is essential to understand handball's physical demands in order to optimize physical training and improve physical characteristics like strength, speed and endurance, which are helpful to delay the appearance of fatigue and to help to diminish the risk of injury (García-Sánchez et al., 2023). Higher ranked handball players display better physical capacities (e. g. anaerobic power, vertical jump) compared to their lower ranked counterparts (Nikolaidis & Ingebrigtsen, 2013), but there is no difference in markers of aerobic capacity such as running pace and total distance covered (García-Sánchez et al., 2023; Nikolaidis & Ingebrigtsen, 2013). Given this information, it is very important that coaches are aware of the differentiating factors for better handball performance, and what are the best means and methods to develop these abilities in their players.

The recent study of García-Sánchez et al. (2023) attempted to summarize the available scientific evidence associated with physical demands during handball official competitions, and they found that strength and endurance are extremely important for handball performance due to factors such as the distance that they have to cover during a match, many times with a high running pace (e.g. sprints, accelerations) and a high number of changes of directions (COD), which are the most frequent high-intensity actions during a game. Besides COD, Povoas et al. (2012) add that other high eccentric-related muscular requirements during the match might be imposed by throws, jumps, and the constant physical contact associated with one-on-one situations. Given these demands, the authors (Povoas et al., 2012) recommend that players should include exercises that

target the ability to repeatedly perform high-intensity activities and to rapidly recover during less intense periods, as well as basic strength training combined with specific power-related actions (e.g., jumps, sprints), which goes in line with the practical applications that can be found in the recent study by García-Sánchez et al. (2023), that advised coaches to improve their players' strength (maximal and explosive-type RFD) and endurance (to repeat high-intensity actions during the entire match) via strength training, landing and COD technique training with disturbances and opposition, deceleration training and endurance training.

Given that handball players need to be well-prepared to deal with the eccentric actions of the sport, such as the constant changes of direction, one effective way to ensure that is through the use of plyometric training, since plyometric exercises use an eccentric muscle action to enhance a subsequent concentric muscle action by using stored elastic energy from the musculotendinous unit, created by the active eccentric phase of the movement (Suchomel et al., 2019a). Through the use of these eccentric-concentric actions, an individual may increase force, power output, and rate of force development, which in turn may lead to improvements in athletic performance (Suchomel et al., 2019a), specifically in handball (Jakšić et al., 2023). One reason to opt for plyometric exercises instead of traditional eccentric-only methods is that the latter are associated with high levels of fatigue, and PT also has the benefit of addressing both ends of the stretch-shortening cycle (Suchomel et al., 2019b).

Besides that, high-intensity interval training is a good way to develop both aerobic and anaerobic energy systems (Buchheit & Laursen, 2013b, 2013a), which have been deemed as important for handball performance due to many different factors (García-Sánchez et al., 2023; Gharbi et al., 2015; Karcher & Buchheit, 2014; Povoas et al., 2012; Wagner et al., 2014; Ziv & Lidor, 2009), and it has shown to be effective specifically in a handball context (Dello Iacono et al., 2015; Viaño-Santasmarinas et al., 2018).

Despite these positive indicators, only recently the knowledge about plyometric training effectiveness in handball has started to be systematized (Jakšić et al., 2023), and it is yet to be done with regard to high-intensity interval training. Given the promising benefits, this systematization is important in order to inform how these practices are performed in the field and if they are based on relevant evidence, to address any uncertainty or variations in practice that might be occurring and to provide reliable findings from which conclusions can be drawn and decisions made (Munn et al., 2018). Given the lack of systematized literature, this work intends to do it by addressing the

methodological characteristics of both plyometric and high-intensity interval training in handball, and to compile and analyze the results regarding its physical and physiological effects in the players, which intends to be helpful to guide the practices of coaches that operate in a handball context.

1.2. STATEMENT OF CONTRIBUTION AND DISSERTATION RELEVANCE

The number of studies about plyometrics (PT) and high-intensity interval training (HIIT) in handball has been rising considerably since 2018, as can be seen in different databases. However, there is a lack of systematized knowledge regarding both topics, and there is an opportunity to start to systematize the literature regarding the implementation of plyometric and high-intensity interval training in handball. Given that, this dissertation pretends to provide a comprehensive review of the literature regarding physical training methods in handball, specifically PT and HIIT, by presenting two studies that intend to fill this gap in the literature.

The first study, about the implementation and outcomes of plyometric training in handball, will be a scoping review. Scoping reviews are used to identify knowledge gaps, set research agendas, identify implications for decision-making, map or clarify the concepts underpinning a research area and the main sources and types of evidence available (Tricco et al., 2016). Scoping reviews are used to present a broad overview of the evidence pertaining to a topic, irrespective of study quality, and are useful when examining areas that are emerging, to clarify key concepts and identify gaps (Tricco et al., 2016). They are also an ideal tool to determine the scope or coverage of a body of literature on a certain topic, and give clear indication of the volume of literature and studies available, as well as an overview of its focus (Munn et al., 2018). Given that scoping reviews are useful for examining emerging evidence and can report on the types of evidence that address and inform practice in the field, as well as the way that research has been conducted (Tricco et al., 2016), they were the chosen way to approach the topic of the first study: plyometric training in a handball context.

The second study, about the methodology regarding the use of HIIT in handball players and its impact on the athletes' physical fitness outcomes, will be a systematic review. Systematic reviews can be broadly defined as a type of research synthesis that are conducted by review groups with specialized skills, who set out to identify and retrieve international evidence that is relevant to a particular question and to appraise and synthesize the results of this search to inform practice, policy and, in some cases, further research, and they follow a structured and pre-defined process that requires rigorous methods to ensure that the results are both reliable and meaningful to end users (Munn et al., 2018). The same authors add that a systematic review may be undertaken to

confirm or refute whether or not current practice is based on relevant evidence, to establish the quality of that evidence, and to address any uncertainty or variation in practice that may be occurring. Conducting a systematic review may also identify gaps, deficiencies, and trends in the current evidence and can help underpin and inform future research in the area (Munn et al., 2018).

With that, the indications for both scoping and systematic reviews (Munn et al., 2018) must be followed and, in this work, it is pretended to identify the types of available evidence regarding plyometric and high-intensity interval training in handball, to clarify key concepts and definitions in handball physical training literature, to examine how physical training research is conducted in a handball context, to identify key characteristics or factors related to physical preparation in handball, and to identify and analyze knowledge gaps in the literature. The intention is to contribute to a better understanding regarding the application of plyometric and high-intensity interval training in handball, enriching the topic with systematized scientific knowledge that allows the readers (coaches, athletes and anyone interested in the topic) to have a better comprehension of the field, and consequently leading to a better application of these types of training in a practical context.

1.3. OBJECTIVES

The objective of this dissertation is to conduct two different reviews summarizing the evidence regarding the strength and conditioning programs utilized in handball and their impact on physical fitness adaptations. The dissertation aims to examine the implementation of plyometric and high-intensity interval training methodologies and explore the main outcomes of these interventions on handball players.

Considering the objectives of this dissertation, two main research objectives will be established, each leading to a separate study:

Study 1

Main goal: to find how plyometric training is implemented in a handball context, and the physiological effects that it provides to handball players

Specific goals of the study 1:

- (i) identify the available evidence regarding the effects of plyometric training interventions in handball players, with an open focus on outcomes adaptations;
- (ii) to examine study design characteristics (e.g., interventions and comparators; the number of groups and randomization; volume-equalization) of the available evidence;
- (iii) to identify key characteristics of methodological training approaches used (e.g., duration; intensity; previous plyometric training experience);
- (iv) to identify and analyze gaps in the knowledge while using an evidence gap map.

Study 2

Main goal: To conduct a comprehensive review of the literature to summarize the main evidence regarding the use of high-intensity interval training (HIIT) on physical fitness outcomes in handball players, while describing the methodological characteristics of the included studies.

Specific goals of the study 2:

- (i) identify the available evidence regarding the effects of high-intensity interval training interventions in handball players, with an open focus on outcomes adaptations;
- (ii) to examine study design characteristics (e.g., interventions and comparators; the number of groups and randomization; volume-equalization) of the available evidence;
- (iii) to identify key characteristics of methodological training approaches used (e.g., duration; intensity; previous HIIT experience);

CHAPTER 2 - LITERATURE REVIEW

2.1. HANDBALL PHYSICAL AND PHYSIOLOGICAL DEMANDS

Handball is a dynamic sport characterized by intensive and intermittent physical exertion. Handball matches are characterized by periods of relatively stable pace interspersed with frequent bursts of intensive physical activity associated with changes in the speed and direction of movement (Lijewski et al., 2020). Handball includes tackles, breakthroughs, claspings, and fast breaks. As the sport has progressed, pace and dynamism, in both attack and defense, has developed and the rules have also been adapted accordingly. (Bøgild et al., 2020)

Handball requires high levels of speed, in particular over short and medium distances (under 30 meters), and, both in training and competition, players must accelerate and change directions quickly while simultaneously performing physical collisions, passing, throwing and jumping actions (van den Tillaar et al., 2020). Handball players must also be able to generate significant power both against small (e.g. shots) and large (e.g. against players, fighting for position) forces (Hammami et al., 2020).

Movements in team-handball are characterized mostly by short accelerations (0-3 m), with stops and changes of direction, and less by sprints (10-30 m) over the entire game field. Straight sprinting is not often used in team-handball competition, but it is still crucial, because it could strongly influence the result of the game because of its importance in the fast breaks (Wagner et al., 2014).

The physical demands of handball include running with and without changes of direction at speeds ranging from walking to rapid sprints, vertical jumping, various types of throwing, and direct physical contact, plus an ability to make multiple sprints at high speed. Several qualitative and quantitative studies of top-level male handball players have demonstrated that key characteristics of the successful professional include endurance capacity, sprint performance, jumping ability, and a high throwing velocity. This is reflected in a highly developed anaerobic endurance. Aerobic endurance is less important, because there are frequent exchanges of athletes during a match. Nevertheless, it has been hypothesized that a well-developed aerobic endurance might help recovery between frequent games during the playing season. (Schwesig et al., 2017)

One specific attribute that is very important is jump height. Offensively, jump height is important for the jump throw, to reach a high vertical position to throw over the block of the rival defensive players, when throwing from backcourt position, or to have more time for throwing (an

increase in flight time) to mimic or to react to the movements of the goalkeeper. On defense, jump height is important to block the rival offensive player when throwing. (Wagner et al., 2014).

To conclude, physical fitness attributes may help differentiate handball players' level in adult, youth, male, and female handball competition (Chaabene et al., 2021; Lemos et al., 2020; Pereira et al., 2018; Romarateabala et al., 2018), so it is important that handball players try to develop this aspect of the game.

2.2. HANDBALLER'S ATHLETIC PROFILE

An analysis of the activity pattern of the players showed marked differences between individual playing positions. High-intensity locomotor activity was much greater in wingers than either backs or pivot players. Backs were found to carry out the largest number of throws, while pivot players exhibited increased agility. Goalkeepers, on the other hand, were shown to possess high explosive strength. The varied physical demands in handball are reflected in the players' anthropometry, which, in turn, correlates strongly with playing positions. (Bøgild et al., 2020).

General position specific differences in handball are wings being lowest, lightest and having lowest fat free mass (FFM) than back-court players and pivots; pivots having higher body mass and FFM than backcourt players, and higher body fat percentage than wings (they are, at the same time, taller and heavier than wings and back-court players). Back-court players and wings had higher jump and reach than pivots, and wings were faster on 30m than pivots. (Bøgild et al., 2020).

Recently, on-court physical match requirements have been studied and differences have been reported between each playing position in elite senior players, mainly wings performing more sprinting/fast breaks and less physical confrontations with the opponent players than other court players. Equally, studies have examined differences in anthropometry and physiological performance characteristics between playing positions in elite senior players. A general finding was that wings were lower, lighter and faster than the rest of team handball players (Bøgild et al., 2020). That is in agreement with what is said by Schwesig et al. (2017), that also report that anthropometric data reveals that the wings were significantly shorter than the backs, goalkeepers and pivots, and that the backs, pivots and goalkeepers conformed to the handball stereotype of unusual tallness. Wagner et al. (2014) also say that wing players are smaller and weight less compared to pivot players and/or backcourt player.

Lijewski et al. (2020) refer that pivot players usually have the most athletic figure in terms of size and weight and relatively short legs. They also add that the backs are characterized by the android body type and low subcutaneous fat content; the backs and pivots have the same strength of back and handgrip; goalkeepers have relatively long upper and lower limbs and high back and handgrip strength; and the wingers are usually slender, have medium length limbs, low body fat percentage, significant extracellular mass and the lowest muscle strength.

To be more specific, Lijewski et al. (2020) said, in their study, that pivot's body mass was the highest by a large margin, followed by that of goalkeepers and backs, and that wingers were

the lightest players on the team. They also add that the upper extremities were longer in goalkeepers, and that the BMI of wingers was the lowest out of all the players, with pivots and goalkeepers having the highest.

Wingers and pivot players were shown to have the shortest lower limbs in relation to the rest of the body, while the reverse was true for goalkeepers and backs. (Lijewski et al., 2020)

Upper limb length index was highest among goalkeepers, and slightly shorter upper extremities were characteristic of wingers and pivot players. The latter also stood out because of the highest proportion of abdominal subcutaneous fat in relation to limb adiposity. (Lijewski et al., 2020)

The diversity in body size and proportions among players results from the specific tasks that each of them has to face. The heavy build and tall stature of pivot players determines their effectiveness on the court, where they face unique tasks associated with being positioned directly in front of the goal area, in between the defenders of the opposing team. Their stature and long upper extremities enable them to effectively block their opponents, increase their reach as well as disorientate opposing defenders and bring chaos in their work; they also provide an advantage in a direct one-to-one confrontation. Their height grants pivots a much wider visual range, while their relatively short legs and low center of gravity increase their stability. Furthermore, short lower extremities tend to move with a higher frequency, which, in turn, is associated with increased speed over short distances (Lijewski et al., 2020).

Goalkeepers tend to have elongated upper and lower extremities, which enables them to cover a larger area of the goal. Additionally, their low body fat percentage grants them a high level of flexibility.

Backs are the central figures when it comes to directing play. The strong jump shots which they are required to perform take highly developed motor skills and considerable agility.

Wingers were found to be the slenderest out of all the players, with the smallest body dimensions. Their relatively low body mass proves an advantage, considering the high level of jumping ability and speed required of players in this position. Athletic physique is of little consequence among wingers, as during a match they do not engage in physical confrontation to the same extent as backs or pivots. In fact, it would prove cumbersome and likely slow them down during a game, preventing them from moving quickly across large distances (Lijewski et al., 2020).

Schwesig et al. (2017) also report better repeated sprint ability (RSA) in wings compared with the other position teammates, having better results in YoYo tests. The authors conclude that it probably reflects, in part, the anthropometric differences (wings being lighter) and the training effect of the playing requirement of the position, with a large number of fast breaks and sprints around 20 meters.

2.3. STRENGTH TRAINING IN HANDBALL

Strength is defined as the ability of an individual or his muscles to exert force against an external resistance. Depending on the sport, athletes might have to display great levels of force against gravity to support their own body mass, manipulate their own body mass or the opponents', or exert force against an object or projectile (Suchomel et al., 2016). In handball, athletes must be able to display all these expressions of force, ones more than others, depending on the position.

Strength assumes great importance to anyone who wants to improve their performance (Grgic et al., 2018). The development of muscular strength is influenced by both neural and morphological factors, like muscle cross sectional area and its architecture, musculotendinous stiffness, neuromuscular inhibition, rate coding, motor unit recruitment and synchronization. These mechanisms are influenced by many factors, especially genetics (Suchomel et al., 2018).

Muscular strength is a critical ability that is directly related to the execution of movements like jumping, sprinting, change of direction and others (Suchomel et al., 2021). Greater levels of strength are related with an improvement of characteristics like a better force-time curve (improved rate of force development), development of potentiation effects, decrease of injury rates and better performance of certain sports movements or skills (Suchomel et al., 2016).

There are many types of strength commonly described in literature. Suchomel et al. (2016) refer isometric strength (the contraction of muscles without articular movement); explosive strength (maximum force in the least time possible); reactive strength (the ability to quickly switch from an eccentric to concentric contraction); and dynamic strength (involves all types of muscle contraction and is defined as the most relevant for the development of athletic skills, due to its similarities with many sports movements). The authors also emphasize that an improvement in dynamic strength might lead to an improvement in other types of strength, and highlight the difference between absolute and relative strength. Absolute strength is the individual's ability to exert the maximum force possible, irrespectively of their body mass, while relative strength is directly related with their body mass.

Lopez et al. (2021) claim that increases in strength levels are directly related with load, and that handling heavier loads induces bigger strength gains. This is related with the principle of specificity and with the previously mentioned neural and structural (or morphological) adaptations.

Handball players are characterized by considerable physical strength, which proves invaluable when it comes to performance. As such, strength training plays an important role among handball players, seeing that it not only increases their fitness, but also reduces the risk of injury (Lijewski et al., 2020). Adherence to strength training might increase the levels of muscular strength and, whenever possible, the SAID principle (specific adaptations to imposed demands) must be respected, considering factors like training volume and intensity, training frequency, rest times, proximity to muscular failure, exercise selection and the speed of the repetitions. When the goal is to increase strength, these variables must be manipulated to ensure the best possible adaptation (Grgic et al., 2018). Going deeper about specificity, the two systematic reviews (Bragazzi et al., 2020; Hadjisavvas et al., 2024) found on PubMed about the effects of resistance training on handball player's strength has shown positive indicators, which translates positively into actions like throwing.

Suchomel et al. (2018) refer that, for strength gains, sets done above 80% 1RM are indicated to reach those adaptations. A reduced number of sets (2-3 per exercise) might be enough to induce those strength gains, but, for more trained athletes, it might be necessary to raise that volume. However, the authors emphasize that an exaggerated number of sets might reduce the athlete's ability to keep the same intensity, what might be detrimental for strength development and, even worse, raise the risk of injury and overtraining. Grgic et al. (2018) say that, when weekly volume is equated, there is not a great influence of the total number of sessions. Given this, coaches must divide their sessions and their respective set-rep scheme in order to respect the athlete's recovery time, optimizing their development.

Regarding rest times, 2 to 5 minutes is the recommended interval to optimize strength gains (Suchomel et al., 2018). Despite other rest strategies that are described in literature, Jukic et al. (2021) affirm that, for strength gains, alternative methods like *cluster-sets*, that imply rest inside the set, present just marginal gains comparatively with traditional methods. Given that, the main aspect to consider to apply (or not) this method, is the time availability to train. However, authors emphasize that this method is a good option to utilize in situations where muscular failure is not pretended, in order to avoid fatigue.

To gain strength, athletes might use unilateral and bilateral exercises. Moran et al. (2021) point the possibility of using greater loads as the main advantage of bilateral exercises, and the

activation of stabilizer muscles as the main advantage of unilateral exercises. They refer that both strategies are efficient, and each one must be applied in the right context, depending whether it's pretended to induce greater mechanic overload, increase the recruitment of stabilizing muscles, or train around some injury. Some examples of exercises commonly used for the lower body are squats and deadlifts (and their variations), and for the upper body are pressing movements (e.g., bench press, shoulder press) and pulling movements (e. g. pull-ups, chin-ups, rows).

Suchomel et al. (2018) refer other aspects like the utilization of free weights, machines, or just bodyweight. In a brief manner, the authors affirm that the use of bodyweight exercises are more appropriate for individuals with low levels of strength, machines when it's pretended to isolate some specific body part, and free weights when it's pretended to induce greater overload and target more body parts simultaneously. The authors also refer eccentric methods as some of the most efficient for strength gains, but these methods must be reserved to more trained athletes and must always be applied carefully, because they are related with greater levels of muscular fatigue.

Independently of the used training means and methods, training monitoring must always be considered, mainly for two reasons: fatigue management and training program efficiency (Suchomel et al., 2021). The authors indicate a varied number of methods of monitoring and load application, namely methods of RM percentages and repetition zones, subjective methods (questionnaires, rate of perceived exertion, repetitions in reserve) and objective methods (velocity-based training), that consider fatigue, readiness and stress levels of the athletes.

Whatever the applied means, methods or strategies, coaches must always pay attention to all the previously mentioned factors when it's time to plan, program, apply, control and monitor the training. Given that there is no perfect *modus operandi* that is appropriate to all situations, it is coaches' responsibility to get as much information as possible about each of the training means and methods, especially their advantages and disadvantages, in order to be able to apply the best solution for the moment or context. That way, coaches will have a bigger theoretical foundation to support their decisions, which will help them to get better results.

2.4. PLYOMETRIC TRAINING IN HANDBALL

Plyometric Training (PT) involves exercises that use the stretch-shortening cycle (SSC), in which a lengthening movement (eccentric) is quickly followed by a shortening movement (concentric). The effective use of the SSC is related to the contributions of different mechanisms, such as the accumulation of elastic energy, pre-load, increase of the time to muscle activation, force enhancement, stretch-reflexes and muscle–tendon interactions that facilitate greater mechanical work production in subsequent concentric muscle actions (Kons et al., 2023).

PT is widely used in many different sports to improve performance, and has been shown to be an effective method of improving a number of physical qualities or performance tasks such as strength, power, jump height, running economy, change of direction, sprint, speed and endurance (Kons et al., 2023; Ramírez de la Cruz et al., 2022). These improvements might be explained by the changes in neural and mechanical properties reported with plyometric training, such as the musculotendinous stiffness and architecture, the strengthening of the elastic properties of connective tissue, or the optimization of the cross-bridge mechanics and motor unit activation (Kons et al., 2023; Ramírez de la Cruz et al., 2022).

Recently, two systematic reviews (Jakšić et al., 2023; Ramirez-Campillo et al., 2020) addressed the effects of plyometric training in handball, and they found positive results in improving several markers that are important for handball performance. Although handball already presents a considerable volume of jumping in its games and training sessions, the study of Jakšić et al. (2023) concluded that, despite that fact, there are still benefits of including additional plyometric exercises in the training regime of handball players, given that plyometric training is effective to develop explosive neuromuscular performance, which is a good choice since its movement structures are essentially similar to those required by a handball game (acceleration, jumping, and COD), and that they are especially valuable to improve the execution of skills such as feints (through improvements in change of direction) and jump shots (through improvements in jumping ability). Those improvements are attributed to factors like enhanced neural drive to agonist muscles, alterations in musculotendinous stiffness, increases in muscle size and architecture, improved intermuscular coordination, greater excitability of the stretch reflex and changes in muscle fibre mechanics (Ramirez-Campillo et al., 2020), some of them which have already been mentioned before.

One of the main benefits pointed in the two mentioned studies (Jakšić et al., 2023; Ramirez-Campillo et al., 2020) is the extremely low rates of injury associated with plyometric training, which is extremely beneficial for players in a sport like handball, which has a considerable number of games throughout the season, with a lot of physical contact between players and many potential injury mechanisms occurring during the games. As mentioned by the authors, PT is a safe form of training that contributes to strengthening tendons and ligaments with an overall strength and power increase, potentially contributing to injury prevention.

Another benefit of plyometric training for handball players is that it can be done without any additional external equipment, through exercises like hurdle jumps, drop jumps or hops (Jakšić et al., 2023; Ramirez-Campillo et al., 2020). Although these studies only focused on lower-body plyometrics, as many of the studies that can be found in literature, there are also benefits in implementing upper-body plyometric exercises (Deng et al., 2023), which are useful in a handball context due to the contribution of the upper limbs to actions such as passing, shooting or fighting for position.

Some important aspects to consider when programming and implementing plyometric exercises are the surface where they are done, the implemented regimen (intensity, volume and density) and the direction, regularity and laterality of the exercises.

Regarding the surface, soft surfaces are more appropriate for maximal dynamic strength production, can be used during the plyometric preparation or general preparation phases of an athlete, are beneficial during the first developmental phase of sprint acceleration and can be used for a wide variety of jumps in the general preparation of top athletes, while hard surfaces are recommended to be introduced after training on soft surfaces and are associated with short ground contact times and bouncing jumps with open knee joint angles, being more associated with the development of power, muscle stiffness, and reactive strength (Montoro-Bombú et al., 2023).

Regarding the direction, regularity and laterality of exercises, some things must be considered. Plyometric exercises must be implemented in a variety of directions, similar to the ones that they will perform in the game, given that performing PT with a combination of different directions is better than a single direction alone (Asadi et al., 2016; Kons et al., 2023). They must be done cyclically and acyclically, given that handball involves both cyclic and acyclic movements, but repeated jumps may be implemented more frequently due to reduced landing forces (Makaruk et al., 2014). Lastly, exercises should be implemented both bilaterally and

unilaterally, but preference should be given to unilateral exercises given that they are more effective than bilateral exercises at increasing both single and double-leg jumping performance, isometric leg press, maximal force, and RFD (Bogdanis et al., 2019).

Regarding PT regimens applied in handball, Ramirez-Campillo et al. (2020) pointed the lack of uniformity in how training programmes were prescribed in the studies implemented in a handball context, advising practitioners to consider general guidelines when formulating plyometric programmes, according to the current scientific evidence, as well as making them appropriate to the individuals with whom they are working. One problem of this advice is that there is still no consensus regarding the optimal volume, intensity and rest times for plyometric exercises, although the recent study of Montoro-Bombú et al. (2023) helped to systematize the knowledge regarding the determination of optimal volume and intensity for plyometric exercises.

In a handball context, plyometric training must be done 2-3 times per week (Kons et al., 2023; Slimani et al., 2016), preferably with a relative low number of total contacts (up to approximately 100) in each training session (Ebben, 2007; Ebben et al., 2014), with rest times that are adequate relatively to the available time of the training sessions (Asadi & Ramírez-Campillo, 2016; Guan et al., 2021; Moreno et al., 2014), and can be combined with other training methods such as strength, sprinting or COD training (Markovic & Mikulic, 2010; Slimani et al., 2016).

2.5. HIIT VS CONTINUOUS TRAINING FOR ENDURANCE IN HANDBALL

Continuous and interval training have been used in practice for a long to increase aerobic and anaerobic capacity of athletes, and their effects on physiological performance markers has also been a constant object of study (Mazoochi et al., 2013). Both methods are deemed as effective to improve physical parameters, although the adaptations provided by both are quite different: continuous training is more associated with increased maximum oxygen intake, capillary network and mitochondrial enzymes in aerobic energy systems, while interval training is more associated with improved levels of anaerobic capacity, lactate pathway enzymes and anaerobic energy creating enzymes (Mazoochi et al., 2013).

Although continuous training has its benefits, as previously mentioned, HIIT seems to be more beneficial in most physical markers of interest (Mazoochi et al., 2013; Milanović et al., 2015; Olney et al., 2017; Seiler & Tønnessen, 2009). Also, as handball is an intermittent sport that primarily uses aerobic metabolism, interspersed by high-intensity actions that greatly tax anaerobic metabolism (Povoas et al., 2012), HIIT attributes seem to be more adequate for handball performance than continuous training.

High-intensity interval training (HIIT) is a time-efficient training method for improving cardiorespiratory and metabolic function and, in turn, physical performance in athletes, that involves repeated short (<45 s) to long (2–4 min) bouts of high-intensity exercise interspersed with recovery periods (Buchheit & Laursen, 2013a, 2013b).

For team sport athletes, as is the case of handball players, the inclusion of sprints and all-out efforts into HIIT programmes has been shown to be an effective practice (Buchheit & Laursen, 2013a), as it mimics some of the requirements that athletes encounter in game situations.

Prescription for HIIT consists of the manipulation of up to nine variables, which include the work interval intensity and duration, relief interval intensity and duration, exercise modality, number of repetitions, number of series, as well as the between-series recovery duration and intensity, and the manipulation of any of these variables can affect the physiological responses to HIIT (Buchheit & Laursen, 2013a).

Regarding its practical application, there are 4 training methods to be used for the implementation of high-intensity interval training: short intervals, long intervals, sprint interval training (SIT) and repeated sprint training (RST) (Buchheit & Laursen, 2013a, 2013b).

In his article about programming HIIT in handball, Buchheit (2014) mentions the use of short intervals, RST, SIT and small-sided games (SSGs). Although long intervals are useful to improve some handball performance markers, their use is not recommended in a handball context, since short intervals provide similar results with more specificity (Viaño-Santasmarinas et al., 2018).

Buchheit (2014) acknowledges the limitations of programming HIIT based on the athlete's VO₂max or Maximal Aerobic Speed (MAS), so he suggests to program HIIT based on the athlete's velocity on the 30-15 Intermittent Fitness Test (IFT). The 30-15IFT is an intermittent incremental test (30 seconds of running at increasing speed, interspersed with 15-second passive recovery periods) that was designed to elicit maximum HR and VO₂ and additionally anaerobic capacity, inter-effort recovery capacity, acceleration, deceleration and COD abilities (Buchheit, 2014). The final speed reached at the test (VIFT) is a composite velocity that considers all physiological variables elicited when performing HIIT, including COD. In other words, the 30-15IFT is highly specific, not to a specific sport, but to the training sessions commonly performed in intermittent sports and, in support of the test's validity, VIFT has been shown to be more accurate than vVO₂max for individualising HIIT with COD in team sport players (Buchheit, 2014). Once the 30-15IFT is performed, the coach has to set the individual running distances on the field for each player, or group the players by VIFT with 1km/h groups and, since most runs in handball have to be performed with COD, the time needed for a COD has to be considered when calculating the target running distance in order to ensure a similar cardiorespiratory load in comparison with straight-line runs (Buchheit, 2014).

To make short intervals more sport-specific, Buchheit (2014) suggests the possible introduction of technical elements like passing, shooting or defensive actions, but caution must be taken in order to not decrease the effort quality, and to make sure that the utilized work-to-rest ratios are actually specific, given that, for example, a defender in a match generally reaches once or twice an attacker per defensive action, and then the game is either stopped (technical fault) or continues with other players.

The sprint forms of HIIT previously mentioned were RST and SIT. RST consists of 2-4 sets of 5-8 sprints of 15-30 meters, interspersed with 14 to 25 seconds of passive or active recovery, which is well-suited for team relay and counter-attacks, and can be performed in shuttle, which, from an injury-prevention perspective, decreases stride length and is likely to decrease hamstring

strain (Buchheit, 2014). The author adds that the sprinting demands found in the games can be used to design position-specific repeated-sprint sequences, such as 20-30m sprints for wingers or 10-15m sprints for backs, for example. SIT consists of 3-6 repetitions of 30-second all-out shuttle sprints over 40-m shuttles, interspersed with 2 to 4 minute of passive recovery and, given their intensity and duration, it is difficult to incorporate the ball during these drills (Buchheit, 2014), which lacks in specificity, but makes it easier to control the intensity of the effort.

Lastly, Buchheit (2014) mentions the use of SSGs, that are games performed with a reduced number of players, in which coaches are requested to encourage players to achieve high intensity during the games. Some modifications that can be made to avoid game breaks that would reduce exercise intensity, are, for example, the restriction of dribbling and defence contacts, not sanctioning infringements of some rules like 'steps' or 'double dribble', throw-on after a goal is immediately made by goalkeepers from their 6-m area, and coaches always available to immediately replace the ball when it is kicked away from the playing area.

A study by Dello Iacono et al. (2015) evaluated the effects of HIIT and SSGs in the physical fitness of handball players and concluded that both are beneficial. However, due to more specificity, the authors recommend that preference must be given to SSGs, stating that they must be included in the training regimen twice per week, given that they are effective in developing strength, aerobic and anaerobic capabilities and supra-maximal intermittent performance, as can be seen by improvements in 10 and 20 meter sprints, vertical jumping, COD and 1RM bench press.

**CHAPTER 3 - PLYOMETRIC TRAINING
PROGRAMS IN HANDBALL: A SYSTEMATIC
SCOPING REVIEW**

SCIENTIFIC ARTICLE 1

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PLYOMETRIC TRAINING PROGRAMS IN HANDBALL: A SYSTEMATIC SCOPING REVIEW

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Review

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Abstract:

This systematic scoping review aimed to comprehensively identify and analyze the available evidence pertaining to the effects of plyometric training interventions on handball players. The search for relevant literature was conducted across prominent databases, including PubMed, Scopus, SPORTDiscus, and Web of Science Core Collection. The eligibility criteria focused on healthy handball players, without restrictions on age, sex, or competitive level, who were exposed to plyometric training interventions, either alone or in combination with other training methods. A meticulous screening process was conducted, whereby 3,195 titles were carefully evaluated, resulting in the inclusion of 35 eligible studies in this systematic scoping review, involving a total of 891 participants. Most studies on plyometric training in handball focused on indoor settings, conducted during the in-season period, and involved tier two athletes. The training frequency typically ranged from twice per week, with a duration of between 5 and 12 weeks, and incorporated some form of progressive overload. The number of total floor contacts varied between 20 and 600. There was a considerable variation in outcomes across the included studies, but most of them demonstrated a positive impact of plyometric training on improving jumping ability, sprinting speed, change of direction, strength, and balance. In conclusion, the predominant focus of the studies was on the lower limb, specifically aiming to assess the intervention influence on variables associated with strength and power. Notably, these investigations consistently highlighted favorable effects on enhancing these parameters among handball players. However, further research is needed to explore the effects of plyometric training in handball, particularly regarding exercise selection, optimal volume and intensity, rest intervals, and tapering protocols.

Key words: team sports, muscle strength, resistance training, stretch-shortening cycle

Introduction

Plyometric training (PT) exercises involve rapid stretching (i.e., lengthening) of a muscle before a rapid transition to a concentric contraction, and this combined action is commonly called the stretch-shortening cycle (Turner & Jeffreys, 2010). PT exercises have been widely researched for their bene-

ficial effects on strength, speed, power, change of direction (COD), throwing, and jumping (Moran, et al., 2021; Slimani, Chamari, Miarka, Del Vecchio, & Chéour, 2016). Those beneficial effects on athletic performance have been observed in multiple team sports such as soccer (Clemente, et al., 2022; Ramirez-Campillo, et al., 2020c), volleyball (Silva,

et al., 2019), basketball (Ramirez-Campillo, et al., 2022), and handball (Ramirez-Campillo, et al., 2020a).

Plyometric training effectively improves athletic performance, does not require much equipment (or any), and can be used anywhere (e.g., sand, water, grass), offering a flexible way to employ in any sport and context (Arazi, Eston, Asadi, Roozbeh, & Zarei, 2016; Lännerström, Nilsson, Cardinale, Björklund, & Larsen, 2021). This fact, combined with effectiveness, may justify the interest and pertinence of this training method. Moreover, PT accommodates well to other training methods (e.g., high-intensity interval training; balance training), i.e., no negative interference or transfer effect has been observed (Chaabene, et al., 2021; Hammami, et al., 2021). Although the body of knowledge regarding PT effects has increased considerably (Ramirez-Campillo, et al., 2020b), some topics still need further research, including optimization strategies for PT volume, intensity, weekly frequency, type of exercise, and its effects on different groups of athletes (Di Giminiani & Petricola, 2016; Ebben, 2007; Ebben, Suchomel, & Garceau, 2014; Matic, et al., 2015; Watkins, Storey, McGuigan, & Gill, 2021).

In team sports such as handball, PT can be substantially promising for improving athletic performance (Chelly, Hermassi, Aouadi, & Shephard, 2014; Mazurek, et al., 2018; Ramirez-Campillo, et al., 2020a), as handball players commonly perform actions such as sprinting, accelerations, jumping or throwing (Karcher & Buchheit, 2014). Additionally, handball is also characterized by frequent physical duels with the opponents and requires accelerations for starting counterattacks or COD to overcome the opponents (Ziv & Lidor, 2009). Indeed, physical fitness attributes may help differentiate among handball players' levels in adult, youth, male, and female handball competition (Chaabene, et al., 2021; Pereira, et al., 2018; Romarateabala, et al., 2020). Given that handball requires well-developed physical fitness, PT can fit into the regular training schedule of athletes, offering some advantages (e.g., easy to use in any context, beneficial effects on strength and power, low interference with other training methods) over other training methods (e.g., eccentric training). Additionally, PT has positive effects on handball athletic performance markers like strength, power, speed, and COD, which translates positively into handball actions like jumping, throwing, running, and sprinting, both linear and multidirectional (Chaabene, et al., 2021; Chelly, et al., 2014; Hermassi, et al., 2014).

The allure of plyometric training lies in its minimal equipment requirements and inherent flexibility. Coaches possess the ability to manipulate various exercise variables to shape the desired training outcomes. These encompass factors such as

frequency and duration (weeks, sessions per week, session duration, total program sessions), intensity (assessed subjectively or quantitatively via tools like video cameras or inertial measurement units), laterality (bilateral and/or unilateral movements), drill types (e.g., squats, skipping, bounding, jumping, hopping), supplemental equipment (e.g., medicine balls, boxes), box height, surface type (e.g., turf, sand, concrete), regimen (sets, repetitions, inter-set and intra-set rest), total repetitions (e.g., jumps, throws), rest intervals between sets, repetitions, and sessions, progressive overload, training period, substitution of jump training, tapering, novel aspects, limitations, considerations, and potential synergies with other training methods. These factors serve as manageable constraints that influence the acute stimulus experienced by players, thereby modulating the intensity and complexity of their training experience.

Although previous systematic reviews (with meta-analysis or scoping focuses) addressed the effects of PT, these did not include analyses of upper-body plyometric training methods (Ramirez-Campillo, et al., 2020a), and they focused on sports other than handball (Ramirez-Campillo, et al., 2020b). In a more recent development, a systematic review (Jakšić, et al., 2023) delved into the impacts of supplementary plyometric training on jump performance of elite handball players. Nonetheless, it is crucial to highlight that this particular review centers solely on lower-limb plyometric training and its distinct effect on vertical jump performance. Limited to a sample size of only six articles, this review exclusively addresses elite male handball players. Moreover, it exhibits certain constraints, notably in its lack of exhaustive insight into the methodological specifics of the encompassed studies. Furthermore, it neglects to present a comprehensive overview of the broader body of literature concerning plyometric training in handball, leaving gaps in understanding within the research landscape.

In contrast to a systematic review, a systematic scoping review aims to fill these gaps and provide a comprehensive overview of the research conducted in this area. A systematic scoping review may be well-suited to provide a broader overview of the available evidence regarding the effects of PT on handball players' adaptations (Munn, et al., 2018). Using a scoping review, we go beyond the narrow focus on lower-limb training and vertical jump performance, as we also include upper-limb plyometric training and consider both male and female athletes. Moreover, we may encompass a broader range of participants, including youth and adults, to explore the potential influences of age and competitive level on training adaptations.

For those reasons, this systematic scoping review aimed to: (i) examine the impact of plyo-

metric training interventions on the physical fitness adaptations of handball players; (ii) examine study design characteristics (e.g., interventions and comparators; the number of groups and randomization; volume-equalization) of the available evidence; and (iii) identify key characteristics of methodological training approaches used (e.g., duration; intensity; previous plyometric training experience).

Methods

This systematic scoping review followed the PRISMA 2020 guidelines and considered the recommendations for scoping reviews checklist (PRISMA-ScR). The protocol was registered at OSF with the code 10.17605/OSF.IO/M65CK on January 11, 2023.

Eligibility criteria

This systematic scoping review only included full-text original articles that had been subjected to peer review. No restrictions were set on language or date of publication. Following the PICOS (population, intervention/exposure, comparator, outcome, study design) approach, the eligibility criteria were as follows:

(Population) Handball and para-handball players of any competitive level, age, or sex.

(Intervention) Jump-based and upper-body based plyometric training for the upper and/or lower limbs and/or combined training, including plyometric training, with the latter comprising at least 50% of the training intervention, considering: i) the number of exercises or ii) time of exposure. No specific time constraint was placed on the training duration, as our objective was to conduct a comprehensive scoping review aimed at identifying various approaches presented in the literature.

(Comparator) Not necessary. Although, in the case of the comparator, it must be regular training-only (i.e., players OR controls exposed to regular on-court training) and/or active controls (exposed to a specific training intervention, not including plyometric training), regardless of being volume-equated. Passive controls would be considered if any study conducted interventions during the off-season.

(Outcomes) Methodological characteristics of training protocol (e.g., frequency, intensity); physical fitness and/or psychophysiological variables measured pre- and post-intervention.

(Study design) No restriction.

Information sources

Two authors (JA and JM) executed the searches for relevant publications on January 12th, 2023, by browsing the electronic databases (PubMed, Scopus, SPORTDiscus, and Web of Science core

collection). In addition to the database searches, (i) manual searches were performed using the reference lists of the included studies to identify potentially relevant titles; (ii) snowballing citation tracking was executed, preferably in the Web of Science; and (iii) two external experts were consulted (as recognized by Expertscape at the *World* level for “plyometric exercise” which was accessed at <https://expertscape.com/ex/plyometric+exercise> on January 12, 2023). The list of the included titles was shared with the experts who employed their search strategy and cross-checked the list. Finally, errata and article retractions were analyzed for any of the included articles.

Search strategy

In the search, the Boolean operators AND/OR were applied. No filters were applied to maximize the chances of identifying relevant studies. Keywords and synonyms were entered in various combinations in all fields:

[Title/Abstract] (Handball* OR “Hand-ball”*)

AND

[All fields/Full text] (plyometric* OR ballistic OR “stretch-shortening cycle” OR reactive OR jump* OR power OR rebound*).

Selection process

Two authors (JR and FMC) independently screened the retrieved records (titles and abstracts). The same authors also independently screened the gathered full texts. Disagreements between the two authors were discussed in a joint reanalysis. In the case of no consensus being reached, the third author (RRC) made the final decision. Where and when required, all co-authors shared opinions about any doubts raised in the selection process to support the final decision. The reference list of the included articles was additionally reviewed by both authors to identify any potentially relevant articles that might have been inadvertently omitted from the selection process. The EndNote™ 20.4 software (Clarivate™) was used for managing records, namely the removal of duplicates either automatically or manually.

Extraction of data

A data extraction sheet, adapted from the Cochrane Consumers and Communication Review Group’s data extraction template, was used to assess inclusion requirements, and subsequently tested on 10% of randomly selected studies (i.e., pilot testing). Two authors (JR and FMC) conducted this process. Full-text articles excluded, with reasons, were recorded. The records were registered in a form created in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

Data items

JR and FMC collected the information and details regarding the study, considering (but not restricted to) the following:

Study details included (but not restricted to): authors, year of publication, study design, treatment, control group (if any), randomization, blinding strategies, the occurrence of injuries, attrition, citation details, country of data collection, funding sources, and competing interests.

Context-related information included (but not restricted to): the moment of the season (e.g., off-season, pre-season, in-season).

Participants-related information included (but not restricted to): the number of participants, sex, age, competitive level (while using the Participant Classification Framework, body mass, height, systematic jump training experience, sport practiced e.g., handball, para-handball, beach handball).

Intervention-related information included (but not restricted to): frequency and duration (the number of weeks; the number of sessions per week; duration of each session; the number of sessions in the entire program; days between PT sessions), intensity (quantification method, if any); if reported, laterality (bilateral and/or unilateral), type of drills (e.g., squats, skipping, bounding, jumping, hopping), additional instruments used (e.g., medicine balls; boxes), box height (if any), type of surface (e.g., turf, sand, concrete), regimen (e.g., sets, repetitions, rest between sets and repetitions); the number of total repetitions (e.g., jumps; throws); rest between sets, rest between repetitions, rest between training sessions; progressive

overload (if any); part of training session; jump training replaced, tapering, novel aspect, limitations or considerations; possible combination with another training method.

Outcomes-related information included (but not restricted to): physical fitness variables (e.g., strength, balance, cardiorespiratory); physical fitness tests used (and the reliability or variability of data, if reported), and the number of time points at which tests were applied over the experimental period.

Results

Study identification and selection

The initial search yielded a total of 3,195 titles (Figure 1). The data were imported to the EndNote™ reference manager software (version 20.2, Clarivate Analytics, Philadelphia, PA, USA). Duplicates (795 titles) were subsequently removed, either automatically or manually. The remaining 2,860 titles were screened for their relevance based on their titles and abstracts. Of those, 2,746 titles were removed. The full texts of the remaining 114 titles were then inspected, and 83 were removed based on the reasons presented in Figure 1. Therefore, 31 articles remained for data extraction and further analysis. Following the revision of the list of 31 articles by the PT experts, two further eligible titles were suggested, reviewed, and integrated. Additionally, two articles were also found eligible in the snowballing citation tracking process. Finally, 35 articles were included in the systematic scoping review.

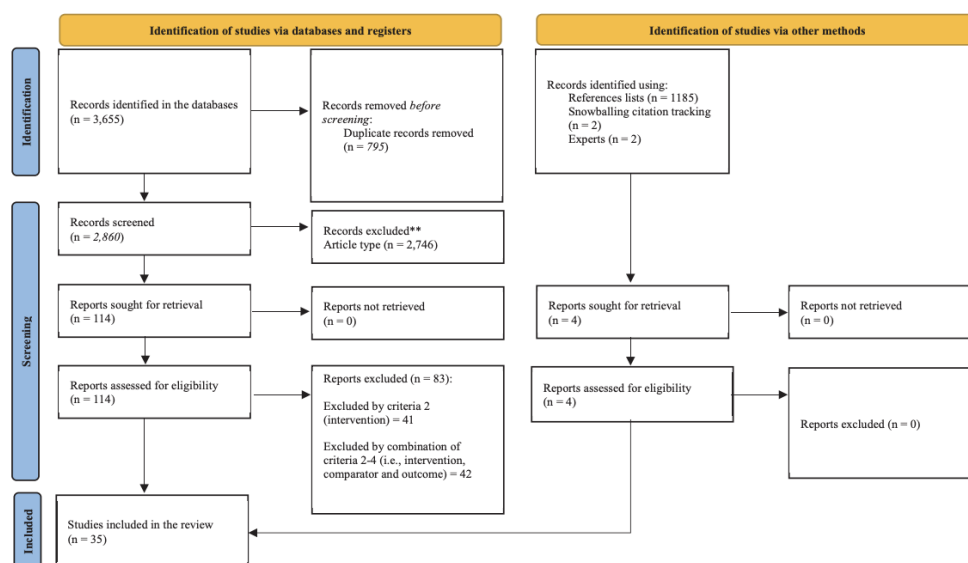


Figure 1. PRISMA 2020 flow diagram.

Study characteristics

Table 1 describes the main study characteristics of the included articles. The overall number of participants was 891. Three studies focused on non-defined tier, 25 studies on tier two, and seven studies on tier three. Moreover, 17 studies were conducted with men, 14 with women, two on both, and two were not defined. Out of the 35 studies, 34 of them were conducted in an indoor handball setting. Regarding the context and randomization, 25 studies were randomized, five were not, while seven others were not defined.

Training intervention characteristics

Regarding the timing of the interventions (Table 1), 23 out of the 35 studies were conducted during the in-season, nine were conducted during the off-season, and only four did not specify in which period of the season the studies had been conducted.

In most of the collected studies, interventions had a frequency of twice per week. However, a significant proportion of studies also had a frequency of three times per week, with values ranging from 24% to 33% across the three tiers. Additionally, most studies had a duration of between five and 12 weeks, with a slightly higher percentage located in the 5-8 week interval. Only two studies had a duration of up to four weeks (Parnow & Hosseini, 2016; Shbib, Rashidlamir, & Hakak Dokht, 2021), and only one (Spieszny & Zubik, 2018) lasted for more than 13 weeks.

Main physical fitness measures analyzed

Considering the assessments performed (Table 1), the following was used: vertical jump (in 30 studies); horizontal jumping (in 5 studies); sprint running (in 23 studies); repeated sprint ability (in 17 studies); change of direction (in 18 studies); cycle-ergometer (in 8 studies).

Characteristics of the training methodologies

Table 2 presents the main methodological characteristics of the training programs implemented in the analyzed handball studies.

Surface

Thirty of the 35 studies did not specify on what kind of surface the plyometric training was done. From the ones that did, two were done on the gym floor (Hammami, et al., 2021; Soto Garcia, Diaz Cruz, Bautista, & Martinez Martin, 2022), one was done on sand (Hammami, et al., 2022), and other on both of them—sand and gym floor (Hammami et al., 2020a). However, given that most of the studies were done with indoor handball players, it is fair

to suppose that most of the studies were done on a gym floor surface, but it is not possible to affirm it without confirmation.

Plyometric training drills

The review of 35 studies identified over 40 exercises, with hurdle jumps being the most common exercise in 18 studies. If we include exercises registered under different names such as lateral hurdle jumps, horizontal hurdle jumps, and drop to hurdle jumps, a total of 23 studies involved hurdle jumps. Hops were the second most common exercise, with 11 studies registering their use, along with seven studies using variations such as single-leg hops, bleacher hops, side-to-side hops, diagonal hops, and front hops, making a total of 19 studies using hops. The third most used exercise was some form of drop jump, with nine studies registering their use, and three studies using vertical, horizontal, and drop to hurdle jumps, respectively, totaling 12 studies. Horizontal jumps were equally common, with ten studies registering their use, and two studies using variations such as horizontal hurdle jumps and horizontal drop jumps, totaling 12 studies. This category may also include other types of horizontal jumps, such as frontal multi-jumps, front and back jumps, coordination ladder jumps, and stride jumps. Four studies registered the use of vertical jumps, but other exercises were also done in a vertical vector, such as counter-movement jumps (bilateral and unilateral), box jumps, rope skipping, various jumping squats (barbell jump squats, split squat jumps, half squat jumps, and squat jumps), depth jumps, and drop jump variations. Lateral jumps and their variations were used in five studies, with another study using skater jumps and another using diagonal jumps (zig-zag jumps). Of the seven studies registering the use of upper body plyometrics, six used dynamic/plyometric push-ups, while the other used a dynamic/throwing bench press. These results show a much greater prevalence of lower-body plyometrics than upper-body plyometrics.

The review found that the only exercise specific to the sport of handball was a jump shot drill. One study also registered two types of bounds—alternate leg and double leg bounds (Ramadan & Elsayed, 2022). In addition, there were four exercises performed without much information provided, including stretched-leg jumps, single and double leg jumps, multi-jumps, and jumps over medicine balls.

Based on this information, it can be concluded that the most commonly used plyometric exercises in handball are hurdle jumps (mostly done horizontally) and vertical jumps, which may include drop jumps, depth jumps, box jumps, counter-movement jumps (CMJs), squat jump variations, and hops.

Table 1. Characteristics of the included studies

Study	N	Handball type	Tier level	Age (M±SD) Sex (F or M)	Type of study	Season period Previous practice in plyometrics	Training duration (weeks)	Sessions per week (n)	Total sessions (n) Adherence (%)	Control group (description)	Assessments performed	Number of assessments
(Alkasasbeh, 2023)	36	Indoor	Tier 2	15-18 F	Two-arm controlled trial (quasi-experimental)	N. D. Yes	10	3	30 ND	Both groups performed PT, although one started with PT+strength training and changed after 5 weeks while the other group did the opposite	1-RM back squat, handball throwing, CMJ, CMJA, 30m sprint, COD, Y6-Y6	3 (pre-intervention, mid-intervention, post-intervention)
(Alonso-Fernández et al., 2017)	EG: 7 CG: 7	Indoor	Tier 2	15.2 ± 0.6 F	Randomized Two-arm controlled trial	In-season ND	8	2	16 ND	CG: standard handball training	CMJ, RSA, 20m shuttle run, anthropometry (height, weight, BMI, body fat)	2 (pre- and post-intervention)
(Aloui et al., 2020)	CG: 15 EG: 14	Indoor	Tier 2	CG: 18.1 ± 0.5 EG: 17.7 ± 0.3 M	Randomized Two-arm controlled trial	In-season ND	8	2	16 ND	Standard handball training, physical training (aerobic and power) and physical education classes	Force-velocity on cycle-ergometer, SJ, CMJ, 30m sprint, 1RM back half-squat, T-half, repeated COD	2 (pre- and post-intervention)
(Aloui et al., 2021)	EG: 14 CG: 15	Indoor	Tier 2	EG: 17.7 ± 0.3 CG: 18.1 ± 0.5 M	Randomized Two-arm controlled trial	In-season ND	8	2	16 ND	CG: resistance + handball standard training	Force-velocity on cycle-ergometer, handball throwing, 1RM bench press, 1RM pull-over, anthropometry (arm muscle volume and body fat)	2 (pre- and post-intervention)
(Busch et al., 2015)	STAB: 10 INSTAB: 9	Indoor	Tier 2	STAB: 16.7±0.6 INSTAB: 17.4±0.9 M+F	Randomized Two-arm controlled trial	ND ND	10	2	20 ND	CG: None	DJ, CMJ, SJ, standing long jump, 20m sprint	2 (pre- and post-intervention)
(Cetin & Ozdel, 2012)	PT: 9 CG: 9	Indoor	Tier 2	13.66±0.5 F	Two-arm controlled trial (quasi-experimental)	ND No	12	3	36 ND	CG: standard handball training	Push-ups, vertical jump height, vertical jump velocity	2 (pre- and post-intervention)
(Chaahene et al., 2021)	EG: 12 CG: 9	Indoor	Tier 2	EG: 15.9 ± 0.2 CG: 15.9 ± 0.3 F	Non-randomized Two-arm controlled trial	In-season Yes	8	2	16 EG: 94% CG: 96%	CG: standard handball training	Sprint running over 5, 10 and 20m, T-test, CMJ, RSI, RSA	2 (pre- and post-intervention)
(Chelly et al., 2014)	EG: 12 CG: 11	Indoor	Tier 2	17.4±0.5 M	Randomized Two-arm controlled trial	In-season ND	8	2	16 ND	CG: standard handball training + strength/circuit training	SJ, CMJ, force-velocity on cycle-ergometer, handball throwing, sprint running over 5, 25 and 30m, anthropometry (stature, skinfolds and body fat)	2 (pre- and post-intervention)

Continuation of Table 1

(Cherif et al., 2012)	EG: 11 CG: 11	Indoor	Tier 3	20:18±1.32 M	Two-arm controlled trial (quasi-experimental)	In-season ND	12	1-2	18 ND	CG: standard handball training	SJ, CMJ, CMJA, DJ, RSA	2 (pre- and post-intervention)
(Dahl & Van Den Tillaar, 2021)	SBT: 13 PST: 12	Outfield	Tier 3	19.5±2.0 F	Randomized Two-arm controlled trial	In-season ND	8	3	24 ND	CG: plyometric and spring training	Ball velocity, trunk velocity, core strength 1RM	2 (pre- and post-intervention)
(Faich et al., 2022)	ST: 11 PT: 10	Indoor	Tier 2	ST: 17.5 ± 2.3 PT: 17.1 ± 2.4 F	Randomized Two-arm controlled trial	ND ND	8	1-2	12 77%	Strength training group	COD tests, squat (bilateral, quarter, lateral), DJ, CMJ, skate jump, sprint running over 5, 10, 20 and 30m	2 (pre- and post-intervention)
(Hammani et al., 2018b)	EG: 14 CG: 14	Indoor	Tier 2	EG: 14.5 ± 0.3 CG: 14.6 ± 0.2 M	Randomized Two-arm controlled trial	In-season Yes	8	2	16 ND	CG: standard handball training	RSTT, Sprint running over 5, 10, 20 and 30m, Modified Illinois, T-half test, SJ, CMJ, CMJA 5-jump, Y-Balance, Stork, 20m shuttle run	2 (pre- and post-intervention)
(Hammani et al., 2021)	EG: 17 CG: 15	Indoor	Tier 2	EG: 16.6 ± 0.5 CG: 16.5 ± 0.8 M	Randomized Two-arm controlled trial	In-season ND	8	2	16 ND	CG: resistance + standard handball training	SJ, CMJ, sprint running over 5, 10, 20 and 30m, modified Illinois, T-half test, 20m shuttle run, RSTT	2 (pre- and post-intervention)
(Hammani et al., 2022)	JST: 24 CG: 18	Indoor	Tier 2	JST: 16.4 ± 0.4 CG: 16.2 ± 0.4 M	Randomized Two-arm controlled trial	Pre-season ND	7	3	21 90%	CG??: standard handball training	SJ, CMJ, 5-jump, sprint running over 5, 10 and 20m, modified Illinois, modified T-test, RSTT, Y-balance, standing stork	2 (pre- and post-intervention)
(Hammani et al., 2020a)	PT: 10 PS: 11 CG: 10	Indoor	Tier 2	PT: 16.2 ± 0.6 PS: 16.4 ± 0.5 CG: 16.5 ± 0.4 M	Randomized Three-arm controlled trial	In-season ND	7	3	21 ND	CG: standard handball training	20m sprint, modified Illinois, modified T-test, RSTT, SJ, CMJ, 5-jump, Y-balance, Stork	2 (pre- and post-intervention)
(Hammani et al., 2018a)	EG: 14 CG: 14	Indoor	Tier 2	EG: 16.6 ± 0.3 CG: 16.6 ± 0.3 F	Randomized Two-arm controlled trial	In-season ND	10	2	20 ND	CG: standard handball training	Sprint running over 5, 10, 20 and 30m, modified Illinois, modified T-test, RSTT, RSSA, SJ, CMJ, CMJA, 5-jump, Y-balance, stork, 1RM half squat	2 (pre- and post-intervention)
(Hammani et al., 2020b)	EG: 17 CG: 17	Indoor	Tier 3	EG: 15.8 ± 0.2 CG: 15.8 ± 0.2 F	Randomized Two-arm controlled trial	In-season Yes	10	2	20 ND	CG: standard handball training	Handgrip strength with dynamometer, maximal isometric back extensor strength, med ball throw, sprint running over 5, 10, 20 and 30m, modified Illinois, SJ, CMJ, CMJA, 5-jump, Y-balance, stork, RSTT	2 (pre- and post-intervention)

Continuation of Table 1

(Hammami et al., 2019)	EG: 21 CG: 20	Indoor	Tier 2	EG: 13.5 ± 0.3 CG: 13.3 ± 0.3 F	Randomized Two-arm controlled trial	In-season ND	9	2	18 ND	CG: standard handball training	Sprint running over 5, 10, 20 and 30m, modified Illinois, modified T-test, SJ, CMJ, CMJA, 5-jump, handgrip strength, isometric back extensor strength, medicine ball throw, Y-balance, stork	2 (pre- and post-intervention)
(Hermassi et al., 2014)	PT: 14 CG: 10	Indoor	Tier 3	20±0.3 M	Randomized Two-arm controlled trial	In-season ND	8	2	16 ND	CG: standard handball training	RSA, SJ, CMJ	2 (pre- and post-intervention)
(Hermassi et al., 2019)	CRT: 12 NSDT: 10	Indoor	Tier 2	20.6±0.48 M	Randomized Two-arm controlled trial	In-season Yes	10	2	20 ND	Both groups had a plyometric intervention, although one not included sport-specific drills and other included	SJ, CMJ, 1RM bench press, 1RM half squat, handball throwing, med ball throwing, RSA	2 (pre- and post-intervention)
(Hermassi et al., 2020)	EG: 10 CG: 9	Indoor	Tier 2	18.5 ± 0.85 M	Randomized Two-arm controlled trial	In-season ND	12	2	24 ND	CG: standard handball training	Anthropometry (weight, FM), SJ, CMJ, 15 and 30m sprint, T-test, 1RM bench press, 1RM pullover, 1RM squat, Yo-Yo	2 (pre- and post-intervention)
(Iacono et al., 2017)	VDJ: 9 HDJ: 9	Indoor	N. D.	23.4 ± 0.6 M	Randomized Two-arm controlled trial	In-season Yes	10	2	20 ND	Both groups performed PT, resistance training and standard handball training	CMJ, 10m and 25m sprint, COD, jump and sprint kinetic and kinematic variables	2 (pre- and post-intervention)
(Kale, 2016)	PT: 10 CG: 9	Indoor	Tier 3	PT: 20.4±3.0 CG: 19.4±3.3 F	Two-arm controlled trial (quasi-experimental)	Pre-season ND	6	2	12 ND	CG: aerobic, sprint, weight and standard handball training	SJ, CMJ, sprint running over 10, 20 and 30m, Wingate, incremental running	2 (pre- and post-intervention)
(Karadenizli, 2015)	16	Indoor	Tier 2	14.57±0.92 F	Non-randomized Single-arm trial	ND ND	10	2	20 ND	CG: None	30m sprint, Illinois, CMJ, standing long jump, sit and reach, static and dynamic balance	2 (pre- and post-intervention)
(Karadenizli, 2016)	EG: 14 CG: 12	Indoor	Tier 2	15.13±0.87 F	Randomized Two-arm controlled trial	In-season ND	10	2	20 100%	CG: standard handball training	30m sprint, Illinois, CMJ, bilateral horizontal jump, sit and reach, static and dynamic balance	2 (pre- and post-intervention)
(Mazurek et al., 2018)	PT1: 14 PT2: 12	Indoor	Tier 3	20.2±2.2 M	Randomized Two-arm controlled trial	Pre-season ND	5	3	14 ND	Both experimental groups had plyometric training, however, one group followed a block periodization and the other had daily undulating periodization	Anthropometry (height, weight, BMI, FM, FFM), incremental test on cycle-ergometer, RSA, CMJ, SJ, DJ	2 (pre- and post-intervention)
(Noulousos et al., 2020)	EG: 19 CG: 14	Indoor	Tier 2	EG: 12.47 ± 0.2 CG: 12.35 ± 0.2 ND	Randomized Two-arm controlled trial	In-season ND	6	2	12 ND	CG: standard handball training	Sprint running over 10 and 20m, T-test, SJ, CMJ (unilateral and bilateral)	2 (pre- and post-intervention)

Continuation of Table 1

(Pancar et al., 2020)	EG: 14 CG: 14	Indoor	Tier 2	EG: 13.07 ± 0.83 CG: 13.07 ± 0.83 F	Randomized Two-arm controlled trial	Pre-season ND	8	3	24 ND	CG: standard handball training	Anthropometry (height and weight), Wingate, balance, 30m sprint	2 (pre- and post-intervention)
(Parnow & Hosseini, 2016)	RT: 10 PT: 10 CT: 10	Indoor	Tier 2	RT: 16.75±0.36 PT: 16.57±0.26 CT: 16.23±0.50 M	Randomized Three-arm controlled trial	ND Yes	4	3	12 ND	CG: resistance training group (including handball training)	Anthropometry (height, weight, BMI, body fat, squat, bench press, Sargent jump, 10m sprint, T-test, Cornish handball)	2 (pre- and post-intervention)
(Ramadan & Elsayed, 2022)	PT: 16	Indoor	N.D.	21.0±1.0 ND	Non-randomized Single-arm trial	ND ND	12	1	12 ND	None	30-15 IFT	2 (pre- and post-intervention)
(Shibb et al., 2021)	EG: 9 CG: 9	Indoor	N. D.	EG: 18.89 ± 2.14 CG: 24.33 ± 5.12 M	Randomized Two-arm controlled trial	In-season ND	4	3	12 ND	CG: both groups were exposed to PT, although one receiving a placebo	Anthropometry (weight, BMI, FM%), Wingate	2 (pre- and post-intervention)
(Soto Garcia et al., 2022)	11	Indoor	Tier 2	23.7 ± 2.26 F	Non-randomized Single-arm trial	ND ND	8	2	16 ND	None	Medicine ball throwing, handball throwing, CMJ (unilateral and bilateral) horizontal jump asymmetry	2 (pre- and post-intervention)
(Spieszny & Zubik, 2018)	ST: 8 PT: 8 CG: 12	Indoor	Tier 3	ST: 23.1 ± 2.53 PT: 21.1 ± 2.17 CG: 23 ± 3.05 M	Three-arm controlled trial (quasi-experimental)	In-season ND	17	2	ND ND	CG: resistance + standard handball training	Anthropometry (height and weight), CMJ, SJ, 10-s on cycle ergometer, handball throwing	2 (pre- and post-intervention)
(Toumi et al., 2004)	PT: 8 WG: 8 CG: 6	Indoor	Tier 2	21±2 M	Randomized Three-arm controlled trial	In-season ND	6	4	24 ND	WG: weight training group; CG: control group (only handball sessions)	SJ, CMJ, maximal isometric leg press extension, dynamic concentric movements in leg press	4 (week 0, week 3, week 6, week 8)
(Van Den Tillaar et al., 2020)	42	Indoor	Tier 2	14.9 ± 0.5 M+F	Two-arm controlled trial (quasi-experimental)	In-season ND	12	2	24 ND	Both groups were exposed to the same intervention, although with an opposite order of introduction.	30m sprint, COD handball specific test, CMJ, CMJA, back squat (load-velocity assessment, handball throwing, Yo-Yo	2 (pre- and post-intervention)

Note. M: male; F: female; Indoor=1, Outdoor=2; N.D.: not described; 30-15IFT: 30-15 Intermittent Fitness test; PT: plyometric training; PS: plyometric training on sand; EG: experimental group; CG: control group; WG: weight training group; ST: strength training group; VDJ: vertical drop jump group; HDJ: horizontal drop jump group; JST: jump and sprint training group; SBT: slingshot based training group; PST: plyometric and spring training group; STAB: plyometric training group on stable surface; INSTAB: plyometric training group on unstable surface; DUP: daily undulating periodization; BP: block periodization; RT: resistance training; CT: complex training; CRT: combined resistance and handball-specific drills; NSDT: resisted training with no specific handball drills; SJ: squat jump; CMJ: countermovement jump; CMJA: countermovement jump with arm movement; DJ: drop jump; TRJ: triple right-leg jump; TLJ: triple left-leg jump; RSJ: reactive strength index; RSA: repeated sprint ability; RSSA: repeated shuttle sprint ability; RSTT: repeated sprint t-test; RCOD: repeated change of direction; COD: change of direction; UB: upper body; LB: lower body; BMI: body mass index; BF: body fat; FM: fat mass; FFM: fat free mass; 1RM: 1 repetition maximum

Table 2. Characteristics of the training interventions, including plyometric exercises

Study	Surface	PT drills	Intensity Box height (if relevant)	NTJ	Laterality	Direction Regularity	Sport- specific	COD	Combined	Regimen (Sets/reps/ rest within and between sets)	RBTS	Periodization	Add/replace Tapering
(Alkasasbeh, 2023)	N. D.	Vertical jumps Horizontal jumps Hops	N. D. N. D.	S1: 420 S2: 444 S3: 492 S4: 516 S5: 556 S6: 556 S7: 568 S8: 600 S9: 492 S10: 486	Bilateral and unilateral	Vertical and horizontal N. D.	NO	NO	YES (sprints)	4-6 x 12-32 / N. D.	N. D.	Progressive overload of training volume	Added N. D.
(Alonso- Fernández et al., 2017)	N. D.	Squat jump Side to side jumps Dynamic push-up Coordination ladder jumps	N. D. N. D.	N. D.	Bilateral and unilateral	Vertical and horizontal N. D.	NO	YES	YES (split squats, mountain climbers, squats)	N. D.	N. D.	Non-progressive	Added N. D.
(Aloui et al., 2020)	N. D.	CMJ Split squat jumps	Maximal effort S1-4: 41.4kg added; S5-8: 55.2kg added S9-12: 67.2kg added; S13-16: 81kg added (through elastic band resistance) N. D.	S1-2/5-6/9-10/13- 14: 60 pS S3-4/7-8/11-12/15- 16: 72 pS	Bilateral	Vertical Cyclical	NO	NO	YES (trunk rotations, hip mobility exercises, squat variations, displacements, skipping with and without COD, sprints with and without COD, push-ups, med ball throws, pull-ups, pulovers, bench press, aerobic training)	5-6 x 6 / N. D.	N. D.	Progressive overload of training intensity	Replaced N. D.
(Aloui et al., 2021)	N. D.	Plyometric push-ups (standard, diamond and wide)	Maximal effort S1-4: 11.2kg added S5-8: 15.6kg added S9-12: 21.2kg added S13-16: 26.8kg added (through elastic band resistance) N. D.	S1-2/5-6/9-10/13- 14: 48 S3-4/7-8/11-12/15- 16: 60	Bilateral	Horizontal N. D.	NO	NO	YES (warm up - exercises regarding running, coordination, trunk rotation, flexibility, jumping, and sprinting, internal and external rotary, flexion, and extension movements of the shoulders, medicine ball throws)	4-5 x 6 / N. D.	N. D.	Progressive overload of training volume and intensity	Replaced N. D.

Continuation of Table 2

(Bischoff et al., 2015)	Stable and unstable surfaces	CMJ Drop jumps	N. D. N. D.	100-150 pS	Unilateral and bilateral	Vertical N. D.	NO	NO	NO	3-4 x 6 / 1-2min	N. D.	Progressive overload of training volume and intensity	N. D. N. D.
(Celin & Ozdol, 2012)	N. D.	Hurdle jumps Jumping back and forth over medicine ball	N. D. N. D.	N. D.	Bilateral	Vertical, lateral, horizontal, backward Cyclic	NO	YES	YES (weight training and bodyweight exercises)	2 x 12-15 / N. D.	N. D.	Progressive overload of training volume	Added N. D.
(Chaabene et al., 2021)	N. D.	Hops CMJs	Maximal height or distance N. D.	W1: 80 W2-3: 90 W4-5: 100 W6-7: 110 W8: 120	Bilateral	Vertical and horizontal Cyclic	NO	NO	NO	4-6 x 10 / 90s	72h	Progressive overload of training volume	Replaced N. D.
(Chelly et al., 2014)	N. D.	Hurdle jumps Drop jumps Dynamic push-ups	Maximal effort 40 cm	W1: 50 W2: 70 W3: 100 W4: 50 W5: 40 W6: 40 W7: 40 W8: 40	Bilateral	Vertical and horizontal Cyclic and acyclic	NO	NO	NO	3x10 to 10x10 / 4-5s / 1min	N. D.	Progressive overload of training volume and intensity	Added N. D.
(Cherif et al., 2012)	N. D.	Drop jumps	N. D. 20, 25, 30, 35 40 and 45cm	W1-4: 40 pS W5-12: 60 pS	Bilateral	Vertical Acyclic	YES	NO	YES (intermittent running, handball shooting, lateral displacements, sprints)	1x10 to 3x10 / N. D.	N. D.	Progressive overload of training volume and intensity	Added N. D.
(Daht & Van Den Tillaar, 2021)	N. D.	Jumps, hops, and jump shots	N. D. N. D.	S1-3: 136 pS S4: 151 pS S5-6: 159 pS S7-8: 180 pS S9-10: 174 pS S11-12: 200 pS S13-14: 188 pS S15-16: 208 pS	Bilateral and unilateral	Vertical and horizontal Cyclic and acyclic	NO	YES	NO	4x6 to 3x10 / N. D.	N. D.	Progressive overload of training volume	N. D. N. D.
(Faich et al., 2022)	N. D.	Drop jumps Unilateral CMJ Skate jumps	Maximal effort N. D.	S1-2: 40 pS S3-4: 54 pS S5-6: 60 pS S7-8: 76 pS S9-10: 94 pS S11-12: 60 pS S13-14: 21 pS	Bilateral and unilateral	Vertical, horizontal and lateral N. D.	NO	YES	NO	1-6 x 4-5 / >2min	Minimum 48h	Progressive overload of training volume with reduced load in the final week	Added Yes

Continuation of Table 2

(Hamami et al., 2018b)	N. D.	Hops Hurdle jumps Lateral hurdle jumps Horizontal jumps	N. D. N. D.	W1: 2: 48 pS W3-6: 96 pS W7-8: 144 pS	Bilateral	Vertical, horizontal and lateral Cyclic	NO	YES	YES (COD training, strength training, HIIT, weightlifting, powerlifting, gymnastics)	6 x 2-6 / 90s	N. D.	Progressive overload of training volume	Replaced N. D.
(Hamami et al., 2021)	Gym floor	Hurdle jumps Horizontal jumps Hops	Maximal effort N. D.	96 pS	Bilateral and unilateral	Vertical and horizontal Cyclic	NO	NO	YES (HIIT/sprints)	2x6 / 10s / 3-5min	N. D.	Non-progressive	Replaced N. D.
(Hamami et al., 2022)	Sand	Lateral hurdle jumps Horizontal jumps Hurdle jumps	N. D. N. D.	W1: 54 pS W2-3: 72 W4-5: 90 W6-7: 108	Bilateral	Vertical, horizontal and lateral Cyclic	NO	YES	YES (sprints)	3-6 x 6 / 90s	2-3 days	Progressive overload of training volume	Replaced N. D.
(Hamami et al., 2020a)	Sand and gymnasium floor	Hops, lateral jumps, horizontal jumps, hurdle jumps	N. D. N. D.	W1: 54 pS W2-3: 72 pS W4-5: 90 pS W6-7: 108 pS	Bilateral	Vertical, horizontal and lateral Cyclic	NO	YES	YES (sprints)	6 x 3-6 / N. D.	2-3 days	Progressive overload of training volume	Replaced N. D.
(Hamami et al., 2018a)	N. D.	Hurdle jumps Horizontal jumps Hops	N. D. N. D.	N. D.	Bilateral and unilateral	Vertical and horizontal Cyclic	NO	NO	YES (weight training, sprints)	4 x 6 / 1-2min	N. D.	N. D.	Replaced N. D.
(Hamami et al., 2020b)	N. D.	Hurdle jumps, Lateral hurdle jumps, Stretched leg jumps, Horizontal jumps, dynamic push-ups	Maximal height/ distance N. D.	W1-2: 120 pS W3-4: 150 pS W5-6: 120 pS W7-8: 150 pS W9-10: 120 pS	Bilateral	Vertical, horizontal and lateral Cyclic	NO	YES	NO	2-10 x 6 / 30s	N. D.	Progressive overload of training intensity	Replaced N. D.
(Hamami et al., 2019)	N. D.	Hurdle jumps, lateral hurdle jumps, stretched leg jumps, dynamic push-ups	Maximal effort N. D.	W1/4/7: 60 W2/5/7: 70 W3/6/9: 80	Bilateral	Vertical, horizontal and lateral Cyclic	NO	NO	YES (sprints and handball shooting)	10 x 6-8 / 90s	N. D.	Wave pattern	Replaced N. D.
(Hermassi et al., 2014)	N. D.	Hurdle jumps Drop Jumps	Maximal height/ distance 40cm	W1: 50 W2: 70 W3: 100 W4: 50 W5: 50 W6: 50 W7: 50 W8: 50	Bilateral	Vertical and horizontal Cyclic and acyclic	NO	NO	NO	5-10 x 10 / 5s / 3min	N. D.	Progressive overload of training volume and intensity	Added N. D.

Continuation of Table 2

(Hermassi et al., 2019)	N. D.	Drop jumps, hurdle jumps	N. D. 30, 45, 50, 55, 60cm	W1: 109-136 pS W2: 126-144 pS W3: 136-152 pS W4: 134-164 pS W5*: 142-172 pS W6: 118-148 pS W7: 124-154 pS W8: 142-162 pS W9-10: 146-176 pS	Bilateral	Vertical and horizontal Cyclic and acyclic	N. D.	N. D.	YES (track and field, gymnastics, team sports and weight training)	4 x 5-20 / N. D.	N. D.	Progressive overload of training volume and intensity	Replaced N. D.
(Hermassi et al., 2020)	N. D.	Diagonal jumps (hops), Depth jumps, Hurdle jumps	N. D. 50cm	S1-5: 20 S6: 22 S7-12: 24 S13-18: 28 S19-24: 32	Bilateral	Vertical, horizontal and diagonal Cyclic and acyclic	NO	YES	YES (circuit training with sprints, med ball and resistance exercises)	1 x 10-16 / 3min	N. D.	Progressive overload of training volume	Replaced N. D.
(Iacono et al., 2017)	N. D.	Vertical and horizontal drop jumps	Maximal height or maximal horizontal forward distance 25cm	30-80 pS	Unilateral	Vertical and horizontal Acyclic	NO	NO	YES (bench press and shoulder press)	5-8 x 6-10 / 10s / 2min	2-3	Progressive overload of training volume	Added Yes
(Kale, 2016)	N. D.	Hurdle jumps Lateral multi jumps Frontal multi jumps	N. D. N. D.	144 pS	Bilateral	Vertical, horizontal and lateral Cyclic	NO	YES	YES (aerobic training, sprint training, weight training)	3x12 / 30-40s / 3min	2-3	Non-progressive	Added N. D.
(Karadenizli, 2015)	N. D.	Lateral jumps Horizontal hurdle jumps Hops	N. D. N. D.	N. D.	Bilateral and unilateral	Vertical, horizontal and lateral N. D.	NO	YES	YES (sprints, pull-ups, med ball exercises)	N. D. / 30-40s / 4-5min	2 days	Non-progressive	N. D. N. D.
(Karadenizli, 2016)	N. D.	Side to side jumps and hops, Vertical jumps, Horizontal jumps, Diagonal jumps, Hurdle jumps, Forward hops	N. D. 40cm	W1-2: 120 W3-4: 120-130 W5-6: 130 W7-10: 140	Bilateral and unilateral	Vertical, horizontal, backward, lateral, diagonal Cyclic and acyclic	NO	YES	NO	2-4 x 3-15 / 1min / 3min	N. D.	Progressive overload of training volume and intensity	Added N. D.
(Mazurek et al., 2018)	N. D.	Hurdle jumps Vertical jumps Stride jumps Front hops Drop jumps Drop to hurdle jumps	Maximal effort 20, 40 and 60cm	87 pS	Bilateral	Vertical and horizontal N. D.	NO	NO	NO	2-5 x 5-10 / 2min	N. D.	Progressive overload of training intensity	Added N. D.

Continuation of Table 2

(Noutsos et al., 2021)	N. D.	Front and back jumps Lateral jumps Half squat jumps Zig zag jumps Horizontal jumps	Maximal effort N. D.	144 pS	Bilateral and unilateral	Vertical, horizontal, backward, lateral and diagonal Cyclic	NO	YES	NO	3x6-8 / 30s / 60s	2 days	Non-progressive	Added N. D.
(Pancar et al., 2020)	N. D.	Rope skipping, single and double leg jumps	N. D. N. D.	W1-3: 180 W4: 164 W4: 240 W6: 246 W7: 264 W8: 270	Bilateral and unilateral	Vertical, horizontal, lateral* and diagonal* Cyclic	NO	YES	NO	N.D. / 1-4min	N. D.	Progressive overload of training volume	Added N. D.
(Parnow & Hosseini, 2016)	N. D.	Vertical jumps Hops Jump squats Dynamic push-ups	Maximal height/ distance N. D.	W1: 80 pS W2: 100 pS W3: 180 pS W4: 150 pS	Bilateral	Vertical and horizontal Cyclic and acyclic	NO	NO	YES (weight training for complex group)	2-3 x 8-12 / 90s-2min	N. D.	Progressive overload of training volume	N. D. N. D.
(Ramadan & Elsayed, 2022)	N. D.	Single leg hops; Bleacher hops; Double leg bound; Alternate leg bound; Squat jumps; Depth jumps; Box jumps	N. D. N. D.	W1: 40 pS W2: 45 pS W3: 80 pS W4: 60 pS W5: 120 pS W6: 90 pS W7: 120 pS W8: 90 pS W9: 180 pS W10: 135 pS W11: 160 pS W12: 120 pS	Unilateral and bilateral	Vertical, horizontal Cyclic and acyclic	NO	NO	NO	1-4 x 10-15 / 1min	N. D.	Progressive overload of training volume	N.D. N. D.
(Shibib et al., 2021)	N. D.	Hurdle jumps; Lateral multi jumps; Frontal multi jumps	N. D. N. D.	144 pS	Bilateral	Vertical, horizontal and lateral Cyclic	NO	YES	NO	3x12 / 30-40s / 3min	N. D.	Non-progressive	Added N. D.
(Solo Garcia et al., 2022)	Gym floor	Drop jumps Lateral jumps Horizontal jumps	N. D. N. D.	59 pS	Bilateral and unilateral	Vertical, horizontal and lateral N. D.	NO	YES	YES (core training, bodyweight and resistance exercises*)	2x5-6 / N. D.	N. D.	Non-progressive	Added N. D.

Continuation of Table 2

(Spieszny & Zubik, 2018)	N. D.	Barbell jump squats Dynamic bench press Hurdle jumps Drop jumps Multi jumps	N. D. N. D.	N. D.	Bilateral	Vertical and horizontal Cyclic and acyclic	NO	YES	NO	3-4 x 5-10 / N. D.	N. D.	N. D.	Added N. D.
(Toumi et al., 2004)	N. D.	Hurdle (bench) jump (with and without pause)	N. D. 35- 50cm	30 pS	Bilateral	Vertical and horizontal Cyclic and acyclic	NO	NO	YES (weight training)	3x5 / 3s (exercise 1) / 3min	N. D.	N. D.	Added N. D.
(Van Den Tillaar et al., 2020)	N. D.	Jumps and hops	Maximal height/ distance N. D.	S1-3: 136 S4: 151 S5-6: 159 S7-8: 180 S9-10: 165 S11-12: 185	Bilateral and unilateral	Vertical and horizontal Cyclic and acyclic	NO	NO	YES (sprints)	2-5 x 8-25 / N. D.	N. D.	Progressive overload of training volume	Replaced N. D.

Note. N.D.: not defined; NTC: number of total contacts; PT: plyometric training; RBS: rest between sets; RBR: rest between repetitions (in seconds); RBTS: rest between training sessions (in number of days); W: week; S: session; pS: per session; HLT: high-intensity interval training.

Number of total contacts with the surface

There was a considerable variation in the number of total contacts per session, ranging from as little as 20 to as high as 600. To facilitate data analysis, the number of total contacts was grouped into different categories.

Fifteen out of the 35 studies had a number of total contacts in the category of 0-100 contacts per session, while 10 presented a number of total contacts between 100 and 200.

Two studies registered higher numbers, with one of them (Pancar, Biçer, & Ozdal, 2020) registering 200-300 contacts in most of the sessions, and the other (Alkasasbeh, 2023) registering more than 300 (up to 600).

Besides that, there are three studies that have numbers that place them in a mixed category. In one the number of total contacts per session ranged from 40 to 180 (Ramadan & Elsayed, 2022), in other the range was 80-120 contacts per session (Chaabene, et al., 2021) and, lastly, in the third, it was 48-144 (Hammami et al., 2018b).

Intensity

Intensity is a parameter that is not typically considered in most studies of plyometric training in handball. Out of the 35 studies reviewed, more than half (approximately 61%) did not mention any defined intensity levels.

Two of the studies (Aloui, et al., 2020, 2021) were done with added weight in the form of elastic band resistance. The remaining 12 studies that considered the intensity, did that by instructing maximal effort, height, or distance, being the most commonly used parameter of intensity.

Box height

Twenty-six out of the 35 studies did not specify any box height, and there are studies that refer to the use of drop jumps or depth jumps without specifying the box height.

From the studies that did consider the box height, six used boxes varying between 30-60cm, one up to 30cm (Iacono, Martono, Milic & Padulo, 2017), and the remaining two studies (Cherif, et al., 2012; Mazurek, et al., 2018) implemented different heights, ranging from 20 to 60cm.

Frequency

Most of the collected studies (approximately 63%) had a frequency of two times per week. However, a considerable portion (approximately 25%) of the studies also registered a frequency of three times per week.

Duration

Most of the studies (32 out of 35) employed interventions that lasted between 5 and 12 weeks, with a slightly higher percentage located in the interval 5-8 weeks. Only two studies (Parnow & Hosseini, 2016; Shbib, et al., 2021) had a duration of up to four weeks (one with tier 2 players and one with non-defined tier players), and only one (Spieszny & Zubik, 2018), with tier 3 players, lasted for more than 13 weeks.

Regularity/cyclical

Regarding the regularity of the exercises, 14 out of the 35 studies implemented exercises in a cyclical pattern, while 11 did it both cyclically and acyclically. Only two studies implemented PT acyclically (Cherif, et al., 2012; Iacono, et al., 2017), and in the remaining eight studies the pattern of PT implementation was not defined.

Direction

Most studies were comprised of exercises (16 out of 35) that were done in both a vertical and horizontal vector, and a considerable number (14) also implemented other directions (e.g., lateral, diagonal) besides those. Three studies (Aloui, et al., 2020; Büsch, Pabst, Mühlbauer, Ehrhardt, & Granacher, 2015; Cherif, et al., 2012) implemented only exercises in a vertical vector, and one (Aloui et al., 2021) implemented only exercises in a horizontal vector.

Laterality

Twenty out of the 35 studies implemented exercises done only bilaterally. Fourteen studies implemented exercises done both bilaterally and unilaterally, and only one study (Iacono, et al., 2017) was comprised of just unilateral exercises.

Change-of-direction

Only in one study (Hermassi, Haddad, Bouhafs, Laudner, & Schwesig, 2019) it was not specified whether the exercises involved a change of direction or not. Of the remaining studies, an equal number of interventions were conducted with and without a change of direction. Fifteen studies did not involve any change of direction, while the other 15 involved a change of direction.

Sport-specific drills

Only two out of the 35 studies registered the use of sport-specific exercises (Dahl & Van Den Tillaar, 2021; Karadenizli, 2016).

There was one study (Hermassi, et al., 2019) that did not specify it, and the remaining 32 did not use any sport-specific exercise.

Rest—intra-set

In terms of the rest used intra-set, 27 out of the 35 studies did not specify any details. Six studies implemented intra-set rest periods under one minute (Chelly, et al., 2014; Hermassi, et al., 2014; Iacono, et al., 2017; Kale, 2016; Noutsos, Meletakos, Athanasiou, Tavlaridis, & Bayios, 2021; Toumi, Best, Martin, & Poumarat, 2004). Two studies (Chelly, et al., 2014; Toumi, Best, Martin, & Poumarat, 2004) used short periods (3-5 seconds, one used specifically 5-second rest (Hermassi, et al., 2014), one specifically 10-second rest (Iacono, et al., 2017), one (Noutsos, Meletakos, Athanasiou, Tavlaridis, & Bayios, 2021) specifically 30-second rest, and one (Kale, 2016) between 30-40-second rest. Two studies (Hammami, et al., 2018b; Karadenizli, 2016) used intra-set rest periods longer than one minute.

Rest—inter-set

There is more information about the inter-set rests compared to the intra-set rests.

Only one study implemented inter-set rest periods shorter than one minute (Hammami et al., 2020b). A considerable number of studies (11) used inter-set rest periods lasting between 60 and 149 seconds, and nine used periods longer than 150 seconds.

One study (Pancar, et al., 2020) used a mix of rest times located in different intervals (1-4 minutes), and the remaining 13 did not mention the use of any inter-set rest period.

Periodization

Most of the studies registered the use of various forms of progressive overload in their interventions.

The most common form of progressive overload regarded training volume, present in 14 out of the 35 studies, with one of them (Falch, Haugen, Kristiansen, & van den Tillaar, 2022) implementing an unload in the final week. The second most common progressive overload regarded training volume and intensity, in seven studies, and a similar number did not implement any form of progressive overload.

Three studies (Aloui, et al., 2020, Hammami et al., 2020b; Mazurek, et al., 2018) implemented a progressive overload of training intensity, and one (Hammami, et al., 2019) implemented a wave pattern throughout their study.

In the remaining three the form of overload was not defined.

Moment of season

Twenty-three out of the 35 studies were done in-season, nine were done off-season, and only four did not mention in what period of the season the studies had been done.

Added/replaced

Seventeen plyometric interventions were added to standard handball training, and 13 replaced the standard training regimen. In the remaining five, it was not specified.

Taper

Only two studies mentioned that they did a taper period in their intervention (Falch, et al., 2022; Iacono et al., 2017). The remaining 33 did not mention anything regarding a taper period.

Physical fitness adaptations after plyometric training

Table 3 presents a comprehensive summary of the evidence regarding the impact of plyometric training on handball performance. The table focuses on various parameters related to jumping, sprinting, change of direction, strength, ball throwing velocity, power, balance, and VO2max.

Regarding jumping abilities, the majority of studies (26 out of 27) reported significant improvements in countermovement jump (CMJ) performance following PT interventions. Similarly, improvements were observed in the squat jump (SJ) in 17 out of 18 studies and in the drop jump (DJ) in two out of three studies. In terms of horizontal jumping, all seven studies evaluating this parameter

reported positive results, indicating that plyometric training can enhance both vertical and horizontal jumping ability.

When examining sprinting, a substantial proportion (19 out of 21) of the included studies demonstrated significant enhancements after implementing PT, highlighting its positive effects on speed-related factors in handball. Change of direction, both repeated and non-repeated, was evaluated in a total of 16 articles, and all of them reported positive results, indicating that PT can improve this important aspect of handball performance.

Strength assessment was performed in 12 articles, and all of them reported positive outcomes, suggesting that PT can contribute to increased strength in handball players. Ball throwing velocity, measured in 10 articles, showed improvements in a significant number of studies (eight out of 10), indicating that plyometric training can positively influence throwing performance.

Other parameters such as power (all nine studies), balance (seven out of eight), and VO2max (all six studies) also exhibited mostly positive results, supporting the effectiveness of PT in enhancing these aspects of handball performance.

Although there were studies evaluating parameters like RSI, MAS, and flexibility, the limited number of articles prevented us from drawing conclusive findings on their effects.

Table 3. Summary of the findings regarding physical fitness adaptations following plyometric training

Study	Main outcomes	Innovations, considerations and limitations
(Alkassasbeh, 2023)	Plyometric-strength group: COD: pre to mid-test +5.5%; CMJ: pre to mid-test +9%; CMJA: pre to mid-test 6.9%; Strength: pre to mid-test + 14%; Endurance: pre to mid-test +12%; Sprint: pre to mid-test +0.1%; Standing throw: pre to mid-test +0.1%; Running throw: pre to mid-test +1.2% Strength-plyometric group: COD: pre to mid-test +6.5%; CMJ: pre to mid-test +7%; CMJA: pre to mid-test +5.9%; Strength: pre to mid-test +11%; Endurance: pre to mid-test +9%; Sprint: pre to mid-test +0.3%; Standing throw: pre to mid-test +0.2%; Running throw: pre to mid-test +0.9%	No additional control group that did not perform the training intervention. Not clear how COD and strength were evaluated. The authors just referenced <2% in all mid-to-post test results. Strange results when comparing Tables 3 and 4. Abusive volume of PT. Longer treatments, more exact measurements, and an analysis of putative mechanistic components are needed.
(Alonso-Fernández et al., 2017)	CMJ height: +1.37cm (4.66%) RSA: -1.21s (7.22%) VO2max: +2.72ml/kg/min (6.19%)	HIIT was the main focus of the study Exercises were done by time and not by sets/reps Results cannot solely be attributed to plyometrics and disregard the other exercises implemented
(Aloui et al., 2020)	Peak power in force-velocity test: +143W (23.1%) 1RM half back squat: +10kg (7.6%) 5m sprint time: -0.1s (8.7%) 30m sprint time: -0.35s (7.2%) T-half test: -0.57s (9.2%) Repeated COD test: -3s (7.1%) CMJ height: +3.6cm (9.1%) SJ height: +3.5cm (9.4%)	Elastic bands were utilized in the PT intervention There is a need to extend observations to cover female players, other age groups, and other skill levels. Despite efforts to match participants across groups, there were some pre-test differences in anthropometric parameters There remains a need to compare the gains in performance with improvements in actual play on the handball court

(Aloui et al., 2021)	Peak power in force-velocity test: +95W (23.3%) Jumping throw speed: +4.1m/s (18.6%) Three-step running throw speed: +4.4m/s (19.1%) Standing throw speed: +4.4m/s (20.4%) 1RM pullover: +6.2kg (22.5%) 1RM bench press: 11.6kg (15.9%)	Elastic bands were utilized in the PT intervention Only study that only implemented upper-body exercises and tests The neuromuscular mechanisms which underpin the improvements reported may be an area for future research Future studies should evaluate and extend these findings to female players, other age groups, and other competition levels There is a need to compare the gains in the test performances with the actual improvement of play on the handball field Having a control group performing the plyometric push-up program without elastic bands would allow for the determination of whether the addition of bands is beneficial for this type of program versus performing unloaded upper extremity plyometrics training, as it is possible that performing the plyometric push-up program without elastic bands may lead to comparable improvements
(Büsch et al., 2015)	SJ height: +3.9cm (11.6%) CMJ height: +1.5cm (3.6%) DJ height: +3cm (11.2%) Standing horizontal jump distance: +3.7cm (1.5%) 5m sprint time: = 10m sprint time: -0.02s (1%) 20m sprint time: -0.05s (1.6%) Figure-of-8 dribbling (s): -0.46s (2%)	Article in German
(Cetin & Ozdol, 2012)	Vertical jump: +3.6cm (12.4%)	Number of repetitions not clear in the article It was not specified how the vertical jump was measured Results cannot solely be attributed to plyometrics and disregard the other exercises implemented
(Chaabene et al., 2021)	5m sprint time: -0.08s (6.45%) 10m sprint time: -0.11s (5.1%) 20m sprint time: -0.13s (3.46%) T-test: -0.87s (7.1%) CMJ height: +2.24cm (10.45%) RSI: 0.14 a.u. RSA: -1.24s (2.3%)	Future studies should address the underlying pattern and mechanisms of adaptations to PT in youth female players Future studies are needed to examine the potential neuromuscular mechanisms underpinning COD performance improvements after PT in youth female players The potential mechanistic factors underpinning RSI adaptations need to be addressed in future studies The explanation for the improvements in RSA has to be substantiated by future studies
(Chelly et al., 2014)	Upper body peak power in force-velocity test: +117W (27.4%) Lower body peak power in force-velocity test: +109W (12.19%) SJ height: +5cm (12.8%) CMJ height: +4cm (9.5%) Sprint velocity: +1.2m/s (11.65%) Jumping shot throw speed: +6.6m/s (22.68%) Three-step running throw speed: +6.2m/s (20.46%) Standing throw speed: +5.4m/s (18.88%)	Findings were limited to one particular category of handball players—elite adolescent males. Future studies should extend the observations to women, to other age groups, and to other levels of competition. Furthermore, observations are also needed with differing intensities and volumes of plyometric training to determine their optimum dosage for this form of preparation.
(Cherif et al., 2012)	SJ height: +0.8cm (2.4%) CMJ height: +0.8cm (2.78%) CMJA height: +0.8cm (2.42%) DJ height (right leg): +0.6cm (2.62%) DJ height (left leg): -0.3cm (0.39%) RSA: -0.1m/s (1.56%)	Players showed many difficulties in maintaining exercise intensity during training sessions Throwing is considered as one of the most important technical skills in competitive handball as it is a major determinant of all actions taken by the players. Studying the effects of the additional combined training program sprint repetition and vertical jump on ball velocity would be useful
(Dahl & Van Den Tillaar, 2021)	7m standing shot: -2.4% Running shot: -3.9% Jump shot: -2.8% Core rotational strength predicted 1RM: -1.3%	PT was not the main focus of the study Results were not presented in a clear way Authors measured different shot metrics but the PT intervention was not adequate for that The focus of the sling-based training was to stimulate the pelvic and trunk rotation strength necessary for shooting. However, a complete shooting sequence involves both the external and internal rotation of both the hips and trunk, and tilting the core in various directions together with various arm joint movements In the future, three dimensional kinematic studies, together with electromyography measurements of the involved muscles should be conducted to investigate how sling-based training influences maximal ball velocity

(Falch et al., 2022)	Bilateral squat relative strength: +0.01kg/BM (2.35%) Quarter squat relative strength: +0.21kg/BM (49.88%) Lateral squat relative strength: RSI: 0.47 a.u. CMJ height: +2cm (20.48%) Skate jump height: +14.7cm (9.36%) 5m sprint time: -0.02s (1.46%) 10m sprint time: -0.06s (2.64%) 20m sprint time: -0.05s (1.32%) 30m sprint time: -0.11s (2.07%)	No control group that did not perform any intervention Generally, strength training group had better results in strength tests (except for the quarter squat) and plyometric group had better results in plyometric tests There is an error in Table 3 (results) regarding the values of the lateral squat improvement in the PT group Magnitude of the COD results is not presented in a very clear way Lack of improvements in the force-oriented CODs in the PT group may be due to insufficient stimulus/reduced number of foot-ground contacts Lack of general improvements in the PT group explained by their low age Lack of improvements in velocity-oriented COD might be due to inadequate exercise selection No possibility of measuring kinematics due to lack of equipment Replication with greater participation and measurements of step kinematics in the velocity-oriented COD is warranted
(Hammami et al., 2018b)	5m sprint time: -0.11s (9.1%) 10m sprint time: -0.16s (7.65%) 20m sprint time: -0.26s (7.32%) 30m sprint time: -0.43s (8.9%) T-half test time: -0.38s (5.3%) Illinois modified test time: -0.6s (4.5%) SJ height: +9.6cm (35.8%) CMJ height: +10.6cm (36.9%) CMJA height: +7.9cm (23.9%) 5-jump test length: +1.1m (12.2%) RSTT total time: -2s (2.4%) MAS 20m shuttle run: +0.5km/h (3.38%) Predicted VO2max: +1.9ml/kg/min (3.99%) Stork balance test (Right): -0.2s (9.5%) Stork balance test (Left): +0.5s (29.4%)	PT was combined with COD exercises, so it is not possible to attribute the results to just one mode of training Right leg balance titles in the table are wrong
(Hammami et al., 2021)	5m sprint time: -0.1s (8.3%) 10m sprint time: -0.16s (7.6%) 20m sprint time: -0.25s (6.8%) 30m sprint time: -0.42s (8.8%) T-half test time: -0.37s (5.1%) Illinois modified test time: -0.55s (4.2%) SJ height: +9.1cm (34.9%) CMJ height: +9.7cm (34.4%) RST total time: -6s (7.2%) MAS 20m shuttle run: +1.1km/h (7.5%) Predicted VO2max: +4.4ml/kg/min (9.2%)	PT was combined with HIIT, so it is not possible to attribute the results to just one mode of training
(Hammami et al., 2022)	5m sprint time: -0.12s (10.8%) 10m sprint time: -0.19s (9.64%) 20m sprint time: -0.24s (6.78%) T-half test time: -0.59s (8.59%) Illinois modified test time: -0.5s (3.85%) SJ height: +8.9cm (34.5%) CMJ height: +8.4cm (33.47%) RSTT total time: -6.2s (7.66%) Stork balance test (Right): +3.11s (80.15%) Stork balance test (Left): +1.68s (40%) Y Balance test right leg forward: +4.3cm (8.19%) Y Balance test right leg background left: +18.1cm (17.1%) Y Balance test right leg background right: +13.1cm (15.7%) Y Balance test left leg forward: +3.8cm (7.38%) Y Balance test left leg background right: +13cm (12.15%) Y Balance test left leg background left: +4.3cm (5.1%)	PT was combined with sprints and was done on sand, so that should be taken into consideration when interpreting the results

(Hammami, et al., 2020a)	Sand surface group: 5m sprint time: -0.22s (18.18%) 10m sprint time: -0.49s (22.58%) 20m sprint time: -0.43s (12.04%) T-half test time: -0.63s (9%) Illinois modified test time: -1.1s (8.46%) SJ height: +8cm (27.97%) CMJ height: +11.1cm (38%) 5-jump test length: +0.7m (6.7%) RSTT total time: -13.8s (15.77%) Stork balance test (Right): +11.87s (365.2%) Stork balance test (Left): +10.77s (244.2%) Y Balance test right leg back: +16.2cm (15.24%) Y Balance test right leg background left: +14.5cm (17.34%) Y Balance test right leg background right: +4.3cm (8.37%) Y Balance test left leg back: +11.4cm (10.3%) Y Balance test left leg background right: +4.2cm (4.85%) Y Balance test left leg background left: +4.4cm (8.99%) Stable surface group: 5m sprint time: -0.08s (6.56%) 10m sprint time: -0.13s (6.1%) 20m sprint time: -0.18s (5.03%) T-half test time: -0.43s (5.99%) Illinois modified test time: -0.6s (4.6%) SJ height: +8.4cm (30.88%) CMJ height: +8.3cm (27%) 5-jump test length: +1.3m (13.27%) RSTT total time: -9.9s (11.39%) Stork balance test (Right): +1.65s (32.29%) Stork balance test (Left): +0.99s (22.35%) Y Balance test right leg back: +17.9cm (17.1%) Y Balance test right leg background left: +10.4cm (12.44%) Y Balance test right leg background right: +3.3cm (6.3%) Y Balance test left leg back: +15.2cm (14.7%) Y Balance test left leg background right: +6.4cm (7.59%) Y Balance test left leg background left: +3.9cm (7.65%)	There were two groups doing PT, but one did it on sand and the other on a stable surface. Results differed considerably in certain parameters
(Hammami et al., 2018a)	5m sprint time: -0.13s (10.4%) 10m sprint time: -0.25s (11.7%) 20m sprint time: -0.4s (10.4%) 30m sprint time: -0.45s (8.1%) T-half test time: -0.37s (5.1%) Illinois modified test time: -0.57s (4.2%) SJ height: +4.8cm (19%) CMJ height: +5.7cm (20.3%) CMJA height: +5.9cm (19.4%) 5-jump test length: +1.3m (15.2%) Back extensor strength: +20.2kg (25.1%) 1RM back half squat: +17.4kg (24%) RSSA total time: -0.8s (1.8%) RSTT total time: -4.7s (5.3%) Stork balance test (Right): +0.92s Stork balance test (Left): +1.03s Y Balance test right leg back: +3.6cm Y Balance test right leg background left: +4.6cm Y Balance test right leg background right: +0.6cm Y Balance test left leg back: +7.6cm Y Balance test left leg background right: +6.7cm Y Balance test left leg background left: 2.3cm	Experimental group did complex training and not regular/standard PT It was not specified how back extensor strength was evaluated During the intervention, both the experimental and control groups reduced their weekly fitness training sessions, maintaining the strength training component but eliminating the circuit training. The complex strength training intervention and associated testing were directed to enhancement of performance in the lower limbs. In contrast, the circuit training element contained exercises designed to strengthen the upper limbs, and its elimination is thus most unlikely to have influenced the statistical comparison between the experimental and control groups following the intervention.

(Hammami, et al., 2020b)	Handgrip right: +62N (26.3%) Handgrip left: +52N (23%) Back extensor strength: +215N (28.4%) Med ball throw: +0.9m (27.6%) 5m sprint time: -0.13s (10%) 10m sprint time: -0.14s (6.7%) 20m sprint time: -0.21s (5.7%) 30m sprint time: -0.36s (7.8%) Illinois modified test time: -0.97s (7.4%) SJ height: +4cm (18.2%) CMJ height: +5.1cm (21.1%) CMJA height: +5.1cm (20%) 5-jump test length: +1.2m (15.3%) RSTT total time: -5.5s (6.1%) Stork balance test (Right): +1.4s (56.4%) Stork balance test (Left): +0.7s (22.2%) Y Balance test right leg anterior: +4cm (4.9%) Y Balance test left leg anterior: +4cm (4.2%) Y Balance test right leg background left: +3cm (4.2%) Y Balance test left leg background right: +7cm (7.5%) Y Balance test right leg background right: +6cm (12.4%) Y Balance test left leg background left: +3cm (7.1%)	The training load was not monitored over the training intervention If the group of players played an official match, then a friendly match or physical work was scheduled for the other group so that the load was the same for the two groups. Nevertheless, there is a difference in feeling between an official match, a friendly match and physical workload
(Hammami et al., 2019)	5m sprint time: -0.9s (6.7%) 10m sprint time: -0.12s (5.4%) 20m sprint time: -0.37s (9.6%) 30m sprint time: -1.19s (20.9%) T-test time: -1.18s (14.5%) Illinois modified test time: -1.1s (7.9%) SJ height: +5.7cm (29.8%) CMJ height: +5.9cm (29.4%) CMJA height: +6.4cm (25%) 5-jump test length: +1.2m (16.3%) Stork balance test (Right): +0.09s (4.2%) Stork balance test (Left): +0.98s (49.9%) Y Balance test right leg back: +5cm (6.6%) Y Balance test right leg background left: +1cm (3.6%) Y Balance test right leg background right: +2cm (3.2%) Y Balance test left leg back: +3cm (3.6%) Y Balance test left leg background right: +2cm (3.1%) Y Balance test left leg background left: +2cm (9.4%) Handgrip right: +81N (43.2%) Handgrip left: +72N (42.5%) Back extensor strength: +175N (26.7%) Med ball throw: +0.8m (27.9%)	Interlimb measurements were not taken, which could have influenced the interpretation of some results Lack of physiological data to explore mechanisms underlying the demonstrated effects, particularly measures of biological maturation Further research is needed to observe the relative role of maturation in the effects of PT on the physical fitness of youth female handball players
(Hermassi et al., 2014)	SJ height: +9.7% CMJ height: +11.4%	Absolute values were not provided and precise percentage values of some parameters were also missing
(Hermassi et al., 2019)	CRT group: RSA total time: -2.9s (6.92%) SJ height: +3.7cm (9.18%) CMJ height: +4cm (9.35%) Jump shot throwing velocity: +11m/s (44%) Running shot throwing velocity: +9.3m/s (32.63%) Med ball throwing velocity: +7.7m/s (41.18%) 1RM half back squat: +15kg (8.7%) 1RM bench press: +19.2kg (30.3%) NSDT group: RSA total time: -2.5s (5.99%) SJ height: +4.4cm (11.34%) CMJ height: +2.9cm (6.73%) Jump shot throwing velocity: +4.9m/s (20.16%) Running shot throwing velocity: +6.5m/s (22.57%) Med ball throwing velocity: +9.1m/s (33.83%) 1RM half back squat: +3kg (1.8%) 1RM bench press: +12kg (18.46%)	PT exercises were combined with other exercises, so results cannot be attributed to PT alone Both groups performed PT exercises It was not practical to classify players into specific playing positions (e. g., pivot, back, wing) and to determine performance improvements on a position-by-position basis. These facts limit the scope of the results and should be considered in the interpretation Authors could not show that higher physical performance leads to an improved match performance. For this purpose, the measurement of the match performance would have been necessary The total volume of training between the two groups was not controlled

(Hermassi et al., 2020)	15m sprint time: -0.1s (3.89%) 30m sprint time: -0.1s (2.35%) T-test time: -0.16s (2.6%) CMJ height: +3.4cm (7.8%) SJ height: +4.8cm (12.5%) 1RM half squat: +23kg (15.2%) 1RM bench press: +15.1kg (18.5%) 1RM pullover: +9.8kg (22%) YoYo IRT distance: +800m (69.2%)	Circuit training was the main focus of the study PT exercises were combined with other exercises, so results cannot be attributed to PT alone There is a need to extend the present observations to players of other age groups and skill levels, including female participants, and to analyze differences in response to this type of training by a playing position
(Iacono et al., 2017)	VDT group: 10m sprint time: -0.08s (3.99%) 25m sprint time: -0.2s (3.7%) COD time: -0.01s (0.84%) CMJ height: +3.71cm (8.7%) HDT group: 10m sprint time: -0.18s (8.58%) 25m sprint time: -0.19s (3.58%) COD time: -0.09s (7.57%) CMJ height: +1.74cm (4.17%)	Both groups did plyometric exercises, one horizontally and the other vertically Further studies are needed to obtain evidence of the optimal combination (i.e., combined vertical and horizontal conditioning regimens) and training dose of exercises (i.e., proportion of vertical and horizontal exercises) required for effective neuromuscular abilities
(Kale, 2016)	SJ height: +2cm (9.4%) CMJ height: +2.9cm (12.6%) 10m sprint time: -0.1s (5.2%) 20m sprint time: -0.11s (3.2%) 30m sprint time: -0.12s (2.47%) Anaerobic power: +0.45W/kg (6%) VO2max: +2.4ml/kg/min (4.9%)	PT exercises were combined with other exercises, so results cannot be attributed to PT alone
(Karadenizli, 2015)	Sit and reach: +5.31cm (21.3%) Standing long jump: +23.75cm (15.36%) Anaerobic power: +40.24 W (6.8%) 30m sprint time: -0.01s (0.2%) Illinois test time: -0.02s (0.12%) CMJ height: +0.72cm (2.57%) Unipedal (left leg) static balance – ellipse area (mm ²): -355.21mm ² (24.7%)	PT exercises were combined with other exercises, so results cannot be attributed to PT alone Subjects were school handball players *Many balance indicators evaluated. Only the one with the most significant result was mentioned.
(Karadenizli, 2016)	Anaerobic power: +38.27W (6.4%) Sit and reach: +3.6cm (13.5%) CMJA height: +4.1cm (10.9%) Standing long jump: +12.59cm (7.13%) 30m sprint time: -0.45s (8.36%) Illinois test time: -1.61s (10%) DB-bipedal slalom-CUC: +63.5% DB-bipedal slalom-PE: -0.3% Static balance – LFEA: -485.53mm ² (30.8%) Static balance – RFEA: -98.63mm ² (6.2%)	PT was combined with sprints, so that should be taken into account when interpreting the results Absence of measurements of core and leg muscle strength
(Mazurek et al., 2018)	VO2max: +3ml/kg/min (6.98%) SJ height: -0.01m (2.4%) CMJ height: -0.01m (2.1%) DJ height: +0.01m (1.8%)	The cycle ergometer test has been previously widely used to evaluate adaptation to physical exercise training, but does not involve the stretch-shortening cycle, which is widely represented in the plyometric training program and could limit the possibility of detecting changes in performance. In addition, sprint cycling is somewhat unfamiliar to handball players More investigations are needed with different intensities and volumes of PT to determine the optimum load for this form of pre-season training. It should be noted that an on-court training program supplemented with plyometric strength training may produce excessive physical loads for the adaptive capabilities of young athletes and, with the lack of a supercompensation phase, it could have a negative influence on subsequent measurements Lack of an additional control group practicing handball without additional jumping or plyometric drills Slight errors in the reported values of some results
(Noutsos et al., 2021)	T-test time: -1.43s (9.39%) 10m sprint time: -0.03s (1.66%) 20m sprint time: -0.15s (3.59%) SJ height: +1.64cm (9.08%) CMJ height: +0.38cm (1.78%) CMJ left leg height: +1.46cm (16.1%) CMJ right leg height: +1.21cm (12.97%)	

(Pancar et al., 2020)	30m sprint time: -0.36s (5.9%) Anaerobic power: +23.32W (7%) Overall Balance Score: -0.49AU (32.67%) Anterior-posterior balance point: -0.44AU (37%) Medial-lateral balance point: -0.21AU (27.27%)	Measurements of the balance scores not well specified
(Parnow & Hosseini, 2016)		CT group and PT group both implemented plyometric exercises Results were not presented in a clear way The structure of the article is not good
(Ramadan & Elsayed, 2022)	VO2max: +4.34ml/kg/min (8%)	Questionable validity of the running economy measures It is necessary to conduct some comparative studies on speed and plyometric protocols in order to gain a better understanding of how to obtain the ultimate improvement of VO2max, running economy, and performance of different players
(Shbib et al., 2021)	Peak power: +56W (9.1%)	PT was used in the intervention, but the focus was on beta-alanine supplementation Studies are required with differing intensities and volumes of plyometric training to determine their optimum dosage. All training sessions were supervised by the investigators, which minimizes variability in training sessions.
(Soto Garcia et al., 2022)	CMJ height: +2.04cm (9.64%) CMJ right leg height: +2.03cm (22.38%) CMJ left leg height: +2.48cm (28.87%) Standing shot throwing speed: -2.72km/h (4.18%) Step running throwing speed: -0.11km/h (0.16%) Dominant hand throwing velocity: -0.32km/h (0.53%) Non dominant hand throwing velocity: +1.46km/h (2.18%) Medicine ball throwing velocity: -0.1m (1.9%) Standing horizontal jump: -9.57 cm (6.08%)	PT exercises were combined with other exercises, so results cannot be attributed to PT alone It is strange that shot throwing velocity decreases in the standing shot, 3-step-running shot and dominant hand shot, and increases in the non-dominant hand There are errors in the calculations of the results, so they cannot be trusted Study was conducted with self-adjusted loads. Intensity was not controlled, only volume
(Spieszny & Zubik, 2018)	CMJ height: +2.7cm (5.7%) SJ height: +1.9cm (4.5%) Power in cycle-ergometer test: +39W (3.8%) Standing throw: +0.8km/h (0.9%) Leaning back throw: +1.4km/h (1.5%) Jumping throw: +0.8km/h (0.9%)	Only study that implemented a wave pattern Slight differences between absolute and relative values
(Toumi et al., 2004)	Maximal isometric force: Week 0-3: +257N Week 3-6: +27N Week 6-8: +15N	Plyometric exercises were combined with weight training, so the results cannot be attributed to PT alone Results not presented in a clear way Pre-mid-post intervention values were not presented for SJ and CMJ
(Van Den Tillaar et al., 2020)	Strength-plyometrics group (pre-to-post): Standing 7m throwing velocity: = 3-step running throwing velocity: +0.4m/s CMJ height: +2.9cm CMJA height: +3cm YoYo distance: +214,3m Squat: +3.15kg 30m sprint time: = COD test: -0.3s Plyometrics-strength group (pre-to-post): Standing 7m throwing velocity: = 3-step running throwing velocity: +0.1m/s CMJ height: +5cm CMJA height: +4cm YoYo distance: +200m Squat: +13.6kg 30m sprint time: = COD test: -0.2s	Both groups did PT, only the training order was different PT exercises were combined with other exercises, so results cannot be attributed to PT alone Results were not presented clearly

Discussion and conclusions

The primary objective of this systematic scoping review was to investigate the implementation of plyometric training within the context of handball training, with a particular focus on the targeted physical fitness variables. The findings revealed that the majority of research conducted on

plyometric training in handball was in the context of indoor handball, with limited studies on beach handball or other game variations. Additionally, most of the studies included tier 2 athletes, indicating that the majority of the population studied was in the developmental stage. The interventions utilized were of a relatively low volume, with work

intensity being a parameter that was mostly disregarded.

The frequency of the interventions was mainly twice per week, with a significant proportion of the studies also implementing three times per week. The majority of the interventions lasted between five and 12 weeks and used mainly cyclic exercises, although a considerable number also included acyclic exercises in conjunction with cyclic ones. Virtually all studies utilized exercises that did not involve any external load, relying instead solely on the body weight of the participants to execute the PT interventions. The exercises used various force vectors, with the majority of them being in the vertical and horizontal planes of movement and primarily bilaterally or bilaterally and unilaterally. Almost all selected exercises were not sport-specific, and many studies did not consider rest periods. However, studies that did register rest periods used mainly inter-set rest periods lasting between one and two minutes.

The majority of the conducted studies adopted a form of progressive overload and were predominantly conducted during the in-season period. Notably, almost none of these studies mentioned the incorporation of any tapering phase. In essence, the primary outcomes of these investigations align with the hypothesis that plyometric training stands as an efficacious method for enhancing muscle power, strength, and balance among handball players, regardless of their competitive level and the extremity of the targeted lower and upper limbs.

Methodological considerations in reporting plyometric training programs

Surface

In this systematic scoping review, focused on the methodological aspects of plyometric training in handball, several limitations were identified in the available information presented in the included articles. One limitation was the lack of clear identification of the type of floor on which the plyometric interventions were performed. Plyometric exercises such as jumps and bounds generate high impact forces on the body. These forces are absorbed primarily by the muscles and bones of the lower extremities when landing on a hard surface such as concrete. On the other hand, when landing on a softer surface, such as sand or turf, the impact forces are absorbed more by the surface itself, resulting in less stress on the muscles and bones. Therefore, the type of floor used for plyometric training in handball may have an important impact on the effectiveness and safety of the training program (Arazi, Mohammadi, & Asadi, 2014; Arazi, Eston, Asadi, Roozbeh, & Zarei, 2016; Lännerström, et al., 2021; Ojeda-Aravena, et al., 2022). Additionally, it is important to note

that different surfaces may also affect the specific mechanics of the exercises being performed, like, for example, landing on sand or turf requiring more stabilization and balance compared to landing on a hard surface (Ahmadi, et al., 2021; Donoghue, Shimojo, & Takagi, 2011; Giatsis, Panoutsakopoulos, & Kollias, 2022; Hammami et al., 2020a).

Although not the main objective of their study, Montoro-Bombú et al. (2023) made some notable observations and recommendations regarding the effects of different surfaces on plyometric training. According to the authors Montoro-Bombú et al. (2023), soft surfaces are more appropriate for maximal dynamic strength production and can be used during the plyometric preparation or general preparation phases of an athlete. Additionally, soft surfaces are beneficial during the first developmental phase of sprint acceleration and can be used for a wide variety of jumps in the general preparation of top athletes. During training on soft surfaces, athletes should avoid heel strikes against the ground to prevent them from being transferred to hard surface work. On the other hand, hard surfaces are recommended to be introduced after training on soft surfaces and are associated with short ground contact times and bouncing jumps with open knee joint angles. Hard surfaces are more conducive to the development of power, muscle stiffness, and reactive strength, so they should be gradually introduced during the specific preparation phase and used in the pre-competitive and competitive phases. A wide variety of jumps that require short ground contact times and are primarily based on fast bouncing can be introduced while training on hard surfaces, as long as metrics such as maximum power output and best reactive strength are monitored. Therefore, it is important to consider the athlete's specific goals and needs when selecting the surface on which to train.

The lack of identification of the type of surface on which plyometric training was performed may result in potential biases in the generalization of the findings. As observed in this systematic scoping review, only 11% of the included articles presented a clear description of the type of surface used, which is a concern since it may not allow for fair comparisons in future discussions. Therefore, it is important for researchers to explicitly report the type of surface used in plyometric training programs to help clarify potential discrepancies in findings and to facilitate the replication of interventions in future studies.

Intensity and box height

Intensity was a parameter that was often not considered by the authors/practitioners of the collected studies. Ramirez-Campillo et al. (2021a) pointed out that it is difficult to identify an adequate marker of plyometric intensity and, the majority of

the studies that did consider intensity in their interventions, did that by instructing maximal effort. In their study, Ramirez-Campillo et al. (2021a) found that the greater performance improvements were associated with maximal intensity, in line with what they found in other meta-analyses, but, in contrast, the same authors referred to a study by Thomas, French & Hayes (2009) where that was not the case. Box height is also a parameter that is often considered to determine intensity when doing drop or depth jumps (Lees & Fahmi, 1994; Prieske, et al., 2019; Taube, Leukel, Lauber, & Gollhofer, 2012; Tong, Chen, Xu, & Zhai, 2022) and it was also mostly disregarded in the studies found in this systematic scoping review that used boxes in their interventions. However, as can be seen in the cited studies, there is still no consensus regarding an optimal drop height when doing this type of intervention.

A recent study by Montoro-Bombú et al. (2023) also provided insight into determining parameters for the implementation of plyometric programs, including the importance of considering factors beyond drop height in determining training intensity. While drop height can be a useful intensity determinant, the authors emphasized that it is not the only factor to consider, as variables such as ground reaction forces, power output, and reactive strength also play important roles. The authors suggest that training intensity can be individualized by evaluating performance parameters such as the optimal height for maximum power output, reactive strength, rate of force development (RFD), ground reaction forces, stiffness, and reactive jump height. However, the authors acknowledge that evaluating all these parameters may be difficult in a team context or in situations where certain measures cannot be obtained. We recommend the reading of Montoro-Bombú et al. (2023) for more information about PT intensity and for recommendations regarding the implementation of PT programs.

Periodization

Periodization is a widely discussed topic in the field of sports science and strength and conditioning. However, it is important to note that some studies have raised questions and concerns about the efficacy of periodization and its definition (Afonso, Nikolaidis, Sousa & Mesquita, 2017; Afonso et al., 2019; Hornsby, Fry, Haff, & Stone, 2020; Kiely, 2012, 2018). While most studies on plyometric training in handball implemented some form of progressive overload, the results were mixed regarding whether the programs were periodized or not, and regardless of the type of periodization used. This was true whether the plyometric training was performed in-season or during the pre-season, and whether it was added to or replaced the standard handball training regimen.

It is important for researchers and practitioners to carefully consider the evidence regarding periodization before implementing it into their training programs (Afonso et al., 2017, 2019; Hornsby, et al., 2020; Kiely, 2012, 2018). Despite these cited discussions regarding periodization lying beyond the scope of this article, it is important to note, as already mentioned above, that there is still no consensus on the definition of periodization. As a result, studying a topic where the definition is not clearly defined can be challenging.

Despite these facts, the study conducted by Lievens, Bourgois, and Boone (2021) aimed to investigate if a specific form of plyometric progressive overload would lead to better results than others. The researchers found that, when the training load was equated, there was no significant difference in the chronic performance benefits between increasing volume, intensity, or both. These results were observed in recreational team sport athletes. Watkins et al. (2021) reported different periodization strategies (undulating, linear, or a combination) in their study on the implementation of PT. However, it is important to consider the previously mentioned concerns regarding the definition of periodization when interpreting findings from studies like this. The lack of a clear and consistent definition of periodization makes it difficult to compare and generalize results across studies. Therefore, future research should strive to use consistent terminology and clearly define their periodization strategies to improve the quality and applicability of the findings.

In their articles that researched the practices of strength and conditioning coaches of different sports and countries, Weldon et al. (2020, 2022) reported that the majority of S&C coaches implemented plyometric exercises year-round. Considering the range of implementation methods and ongoing discussions about periodization in plyometric training literature, it is crucial for sports scientists and coaches to work collaboratively to determine optimal strategies for PT implementation and to arrive at more definitive conclusions on periodization. By incorporating a more standardized approach and ensuring that key variables are monitored and reported, such as type of surface used, progression models, and program periodization, we can develop a better understanding of the most effective PT methods for different sports and athletic populations. Furthermore, by combining the expertise of both researchers and practitioners, we can ensure that these methods are effectively integrated into training programs and have a positive impact on athletic performance.

Tapering

One limitation found in the included articles of this systematic scoping review was the lack

of information about tapering, as only two out of 35 studies mentioned the utilization of any taper strategy. Tapering is an essential component of training programs that involves reducing training volume and intensity prior to a competition, with the aim of maximizing performance (Bosquet, Montpetit, Arvisais, & Mujika 2007; Le Meur, Hauss-wirth, & Mujika, 2012; Murach & Bagley, 2015). The absence of information about tapering in the majority of studies limits our understanding of how it affects the effectiveness of PT interventions in handball players. The only study we found specifically addressing tapering in PT was a systematic review with meta-analysis (Ramirez-Campillo, et al., 2021b). The authors of the review (Ramirez-Campillo, et al., 2021b) recognize that the implementation of taper strategies can be difficult over the course of competitive seasons due to the high volume of matches and technical-tactical workouts typically faced by elite players in team sports. However, the authors (Ramirez-Campillo, et al., 2021b) note that adequate tapering approaches have been shown to be very effective during training periods lasting between four and eight weeks, such as pre-season or less congested in-season phases. Moreover, they also found that tapering strategies seemed to be equally effective for both shorter (≤ 7 days) and longer (> 7 days) time periods, and that lower reductions in training volume ($\leq 40\%$) appeared to be more effective in significantly improving jumping performance.

To date, the research on tapering strategies for PT and team sports is limited (Vachon, et al., 2021). Therefore, it is crucial for future studies to consider tapering strategies and evaluate their effects on PT and team sports. It is recommended that the authors of future interventions focus on tapering strategies to provide more information about the optimal ways to implement tapering in a team sport context, given the typically congested schedules that teams face. By doing so, we may gain a better understanding of how to best implement tapering and its effects on PT and other types of training in team sports.

Type of exercises (and if they were sport-specific/involving COD)

In the section “Study characteristics”, it was noted that the studies included in this systematic scoping review registered over 40 different exercises. However, only one exercise was deemed to be sport-specific, as it involved the use of a ball and was utilized in only two studies. Additionally, there was no clear consensus on the use of change of direction (COD) exercises, with nearly an equal number of studies utilizing them as those that did not. The most commonly implemented exercises were variations of hurdle jumps, hopping, drop jumps, horizontal jumps, and vertical jumps. These are exercises commonly used in PT (Weldon, et

al., 2020, 2022) and they have been proven effective in improving some physical fitness parameters on many occasions (Kons, et al., 2023; Slimani, et al., 2016).

It is noteworthy that the majority of the studies included in this systematic scoping review only incorporated plyometric exercises for the lower body, with a limited number of studies including any form of plyometric exercise for the upper body. Considering that handball requires coordinated movements of both the upper and lower body, it is surprising that upper body plyometric exercises are not more commonly employed in training. As noted by Deng et al. (2023), there have been multiple reviews and meta-analyses published that examine the effect of lower limb plyometrics on various physical fitness indices, but the same has yet to be done regarding PT for the upper limbs. The authors (Deng, et al., 2023), reviewed 15 studies that combined PT for both upper and lower limbs and found that, for the most part, the combination had advantages for both upper and lower body physical performance of athletes. This indicates not only increased flexibility, upper body muscle strength and power, but also substantial gains in lower body muscle power, sprint speed, and agility. Given these findings, in a sport like handball, which includes actions for both the upper and lower limbs, coaches should be encouraged to implement plyometric exercises for both parts of the body to enhance the physical performance of their players.

Despite handball being a sport that already incorporates a considerable number of plyometric actions like jumping and changes of direction, Jakšić et al. (2023) considered that there is value in adding PT exercises to regular handball training. A study by Asadi et al. (2016) emphasizes the importance of performing exercises in different movement vectors to improve change of direction (COD) and the ability to move in different directions. Asadi et al. (2016) highlights that, since vertical jump exercises are not specific to COD, they do not show any effect on COD performance. However, when exercises are specific to COD, such as lateral bounds, side hops, and angle hops, the training program has a positive effect on COD performance. Despite the previously mentioned findings, the umbrella review of Kons et al. (2023) only found benefits in implementing plyometric exercises to improve COD in two of the studies presented in their review, while the other studies that evaluated the benefits of PT to improve COD had unclear effects. This information should be considered cautiously when planning PT.

Regularity

The majority of studies included in this systematic scoping review utilized a cyclic pattern for their plyometric exercises, although a significant proportion also incorporated both cyclic and acyclic

patterns. A study by Makaruk, Czaplicki, Sacewicz, and Sadowski (2014) found that using repeated jump training methods might be more effective than single jumps for reducing vertical landing force in common plyometric exercises, but both methods improved jump height. The authors concluded that repeated jumps during PT might reduce landing force and improve jumping performance simultaneously, whereas single jumps improved jumping performance and changed the landing pattern for a stiffer technique in common plyometric exercises without reducing landing force.

Considering that handball involves both cyclic and acyclic movements, both types of patterns should be included in PT programs aimed at improving handball performance. However, given the previously mentioned findings by Makaruk et al. (2014), repeated jumps may be implemented more frequently, given the reduction in landing forces.

Laterality

Although it is common to perform actions with both legs in handball, such as jumping to block, and with only one leg, such as jumping to shoot, it is important to note that unilateral movements are more prevalent in the game. Therefore, it is somewhat surprising to find that a considerable percentage of the studies in this systematic scoping review implemented only bilateral exercises. Nevertheless, it is encouraging to see that there was an almost equal number of studies conducting their exercises either bilaterally or bilaterally and unilaterally, indicating that some coaches and researchers are aware of the importance of both types of movements in handball performance. This goes hand in hand with the study of Bogdanis et al. (2019), which found greater improvements with unilateral PT compared to bilateral PT. The authors (Bogdanis, et al., 2019) reported that unilateral PT was more effective than bilateral training at increasing both single and double-leg jumping performance, isometric leg press, maximal force, and RFD. They detailed that the main finding of their study was that unilateral lower limb PT was effective at improving both single and double-leg explosive performance, while an equal volume of bilateral training only improved bilateral performance. One possible explanation for the superiority of unilateral plyometric exercises could be related to neural factors. The authors (Bogdanis, et al., 2019) explain that, during unilateral plyometric exercises, muscles contract at slower velocities closer to their optimal level, resulting in a greater impulse. In contrast, during bilateral vertical jumps, muscles contract at greater velocities, which, due to the force-velocity relationship, produce less force. In handball, where both unilateral and bilateral movements are common, coaches should consider implementing both types of exercises, and give special attention to unilateral plyo-

metric exercises due to their potential effectiveness in improving explosive performance.

From a biomechanical standpoint, unilateral plyometric exercises tend to place greater demands on the stabilizing muscles of the core and lower extremities, as the body must work to maintain balance and control during the movement (Bogdanis, et al., 2019).

On the other hand, bilateral plyometric exercises tend to generate greater forces and power outputs than unilateral exercises, as both limbs can contribute to the movement. This can be particularly beneficial for activities that require symmetrical or coordinated movements, such as sprinting, jumping, and throwing. Additionally, bilateral exercises can help to develop the elastic properties of the muscles and tendons, which can improve energy storage and return during explosive movements (Bogdanis, et al., 2019; Wallace, et al., 2010).

With this information in mind, coaches should implement exercises in their PT training programs that aim to improve performance either bilaterally or unilaterally, in order to adequate their training intervention to the scenarios that players will find in the game. Given the previously mentioned findings, it might be reasonable to affirm that unilateral plyometric exercises should be given preference in relation to bilateral ones, although the systematic review of Slimani et al. (2016) affirms that the combination of unilateral and bilateral jump drills seems more advantageous to induce significant performance improvements during high-intensity short-term PT in team sport players.

Direction

Most of the studies in this systematic scoping review implemented exercises in both the vertical and horizontal vectors, but a considerable amount also introduced other directions (e.g., lateral or diagonal). As noted by Asadi et al. (2016), performing PT with a combination of different types of plyometric exercises such as, for example, drop jumps, vertical jumps and standing long jumps, is better than a single form of exercise alone. As previously mentioned, the authors emphasize the importance of implementing COD-specific plyometric exercises in order to improve COD performance. They found that exercises such as lateral bounds, side hops, and angled hops had a positive effect on COD performance, while non-specific exercises such as vertical jumps did not. The reason for this is attributed to the different movement characteristics and the use of stretch-shortening cycle (SSC) characteristics. In COD movements, the SSC is utilized in a different way compared to vertical jumps, highlighting the importance of specificity in PT programming.

The umbrella review by Kons et al. (2023) shows that, in the studies conducted with team sports athletes, PT exercises done in different direc-

tions had moderate-to-large effects on improving various performance parameters, showing the greater relevance of PT to enhancing performance in this target population.

From a biomechanical perspective, the selection of exercises in plyometric training can have a significant impact on training adaptations. Exercises that emphasize movements in different planes can place varying demands on the musculoskeletal system, which can lead to differences in muscle activation and adaptation. For instance, exercises that target sagittal plane movements, such as vertical jumps or forward bounds, tend to emphasize the quadriceps and hip extensors, while exercises that target frontal or transverse plane movements, such as lateral jumps or rotational bounds, engage different muscle groups. Furthermore, exercises that involve landing in different directions can enhance the body's ability to absorb and dissipate force. Therefore, coaches should strive to implement exercises that are appropriate for the specific situations that occur more frequently in handball competitions, which involve movements in all planes.

Number of total contacts with the surface

As said in the 'Study characteristics' section, there is a considerable disparity in the number of total ground contacts per session applied in the studies. Despite some studies recommending relatively low volumes of plyometric training (Ebben, 2007; Ebben, et al., 2014), and highlighting that higher volumes were not more effective than lower volumes, this systematic scoping review found one study (Alkasasbeh, 2023) that utilized as much as 600 ground contacts per session. However, it is important to note that this was the exception rather than the rule, since almost all the studies used less than 200 contacts per session, with the majority of them staying under 100 contacts per session.

It would be useful to see if the studies using lower volumes were equally effective compared with the ones with higher volumes. However, the six studies that registered the lower volumes are not adequate to draw conclusions, since four of them (Cherif et al., 2012; Hermassi, Laudner, & Schwesig, 2020; Soto Garcia, et al., 2022; Toumi, et al., 2004) combined PT with other training methods, one (Hermassi, et al., 2014), that lasted only eight weeks, reported some improvements in some parameters for the plyometric training group, but not for others, and the one by Chelly et al. (2014), that also lasted eight weeks, was the one that has shown the most promising results. However, even if these six studies coincided in their findings, it would still be a reduced sample to evaluate the effect of PT interventions with an average of up to 60 ground contacts per session compared to the ones with slightly higher volumes.

As handball is a sport that already has a considerable amount of jumping volume and other plyometric movements from the sport itself, some might ask if there are additional benefits of performing PT. The study by Jakšić et al. (2023) addressed that question and concluded that, when done two times per week for, at least, six weeks, PT in addition to handball practice is beneficial to athletes. However, it is important to note that the study has some limitations, in particular the fact that they included just six studies, and that there is no recommendation regarding the number of total ground contacts, so coaches cannot get any useful and practical information regarding this specific parameter.

Rest

Regarding intra-set rest intervals, most of the studies in this systematic scoping review did not consider this parameter. That did not happen so much with inter-set rest intervals, since a considerable number of studies specified that parameter.

Intra-set rest interval time is a topic that is not much studied in plyometric training literature. Two studies (Asadi & Ramírez-Campillo, 2016; Moreno, Brown, Coburn, & Judelson, 2014) addressed, and found, contrasting results regarding rest effects on different physical parameters. Given that, we suggest that intra-set rest intervals in plyometric intervention should be more researched, so we can give coaches and practitioners more information regarding this topic.

Regarding inter-set rest intervals, studies affirm that better results are reached with, at least, two minutes of inter-set rest intervals to improve change of direction (Asadi, et al., 2016) or three minutes to improve power (Willardson, 2006). However, the studies by Ramírez-Campillo et al. (2014) and, more recently, Guan et al. (2021), do not support those affirmations and have not shown greater benefits of longer (>2min) rest times compared to shorter (30s-1min) to a vast number of parameters.

Most of the studies included in this systematic scoping review utilized inter-set rest intervals that were superior to one minute. While this is not necessarily wrong, the conflicting findings of the aforementioned studies raise questions regarding whether the applied rest intervals were ideal. Given that time is a limited resource and that in handball, as in other team sports, there might not be enough time to optimally develop physical abilities, it may be beneficial to conduct more studies to determine whether longer rest intervals are necessary when doing plyometric exercises to reap greater benefits.

PT frequency and duration

Most of the studies in this systematic scoping review implemented a frequency of two plyometric training sessions per week, and a considerable

number did it three times a week. Given that handball players and coaches already have to dedicate their time to improve other aspects of the game, that seems to be an adequate number of training sessions devoted to PT.

Regarding the duration of the interventions, most of the studies lasted from five to 12 weeks. The general recommendations state that more than eight weeks of systematic application of PT is necessary to improve physical performance in elite players, but short PT interventions (<8 weeks) have the potential to enhance a wide range of athletic performance parameters (e.g., jumping and sprinting) in children and youth amateur players (Slimani, et al., 2016).

While it is a somewhat common practice in sports science studies, due to a different number of factors, to have study durations that are somewhat reduced, it would be useful to have longer studies researching the effectiveness of, not only PT, but also other training means and methods for greater periods of time. Given that most of the team sports' seasons last almost a year, it would be useful for sports scientists, coaches and practitioners to be able to know the effects of some training interventions during longer periods of time, although we recognize the difficulty of doing that.

Main physical fitness adaptations observed

Vertical jumping

Jumping was the most common assessment performed, especially some forms of vertical jumping. Vertical jumping was evaluated in a total of 28 articles, specifically by countermovement jump—with or without arm movement—in 27 articles, squat jump in 18 articles, and drop jump in three articles. The results between them were mixed, ranging from negative changes in the CMJ and SJ (Mazurek, et al., 2018) to improvements of 38% (Hammami et al., 2020a) and 35.8% (Hammami, et al., 2018b) in the CMJ and SJ, respectively. Despite being present in only three articles, the drop jump values were also mixed, ranging from a decrease of 0.39% (Cherif, et al., 2012) to improvements of 11.2% (Büsch, et al., 2015).

It is hard to find a justification for the disparity in the vertical jumping results, as there is not a single factor that we can use to justify the discrepancy in values. The authors of the study with the poorest results (Mazurek, et al., 2018) point out some factors like short study duration, athletes' level, lack of progressive overload and absence of other training methods (e.g., resistance training) as a possible cause for the results. Although we found studies with all these characteristics that presented considerable differences in the results, maybe the combination of these characteristics (short study duration/reduced number of sessions,

with the lack of progressive overload and no combination with other training methods in this specific population of tier 3 athletes) can justify the weak results in this specific study. The study by Cherif et al. (2012) presented a decrease in a drop jump performed unilaterally with the left leg, and, as the athletes only performed bilateral drop jumps, that goes in hand with the already mentioned findings of Bogdanis et al. (2019) that have shown that unilateral lower limb PT is effective at improving both single and double-leg explosive performance, while an equal volume of bilateral training only improves bilateral performance.

Some of the commonalities of the studies with the best results (Hammami, et al., 2020a; Hammami, et al., 2018b) were that they were performed with young age athletes (between 14-16 years), with interventions lasting 7/8 weeks and with a combination of the same exercises (hops, hurdle jumps, lateral jumps and horizontal jumps) done cyclically, in multiple vectors and implementing a progressive overload of training volume. Both were combined with other training methods, although different ones, and an important feature of the Hammami et al. (2020a) study that might have influenced the results was that a part of the group performed the intervention on sand.

In their article that studied the effect of PT on the jumping performance of handball players, Ramirez-Campillo et al. (2020a) suggest that the improvements in vertical jump height after PT probably encompass potential mechanisms such as enhanced neural drive to agonist muscles, alterations in musculotendinous stiffness, increases in muscle size and architecture, improved intermuscular coordination, greater excitability of the stretch reflex and changes in muscle fiber mechanics. As noted by Saéz-Saéz De Villarreal, Kellis, Kraemer, and Izquierdo (2009), the specific effects of plyometrics on vertical jump performance in different types of jumps could be of particular importance, since PT is more effective in improving vertical jump performance in SSC jumps because of the enhancement of the subjects' ability to use the elastic and neural benefits of the SSC, what could be attributed to differences in the use of SSC characteristics, as an SJ consists mainly of a concentric phase, whereas a CMJ involves an eccentric and concentric phase. The authors (Saéz-Saéz de Villarreal, et al., 2009) affirm that plyometrics produce slightly better effects in the fast SSC jumps (i.e., DJ) than in the concentric-only jumps (i.e., SJ) or even the slow SSC jumps (i.e., CMJ), so it is plausible to conclude that plyometric training effects are expected to be greater on DJs and CMJs than on SJs. To explain the difference in the effects of plyometric training between them, the biomechanical differences between the slow and fast SSC jumping exercises should be considered, as there are substantial

differences in the mechanical output and jumping performance between slow SSC vertical jumps (e.g., CMJs) and fast SSC vertical jumps (e.g., DJs), and factors of jumping technique like corporal position, movement amplitude and ground-contact time represent some of the most important factors to consider when designing PT programs (Saéz-Saez de Villarreal et al., 2009).

Horizontal jumping

Horizontal jump ability was measured mainly by a standing long jump or a 5-jump test, in seven articles, and they have shown improvements from 1.5% (Büsch, et al., 2015) to 16.3% (Hammami, et al., 2019). Regarding horizontal jumping results, we can speculate that the poorest results (Büsch, et al., 2015) might be attributed to the fact that some of the interventions were made on unstable surfaces (Lesinski, Prieske, Demps & Granacher, 2016; Lesinski, Prieske, Beurskens, Behm & Granacher, 2018a; Lesinski, Prieske, Borde, Beurskens & Granacher, 2018b; Prieske, et al., 2013, 2015; Prieske, Demps, Lesinski & Granacher, 2017), and the best results (Hammami, et al., 2019) might be attributed to the low age of the athletes who were 13 years old (Peitz, Behringer, & Granacher, 2018; Radnor, et al., 2018), since this is the most distinguishable factor of that study, and they have presented great improvements in other parameters as well.

Although there are similarities in some mechanisms between vertical and horizontal jumps, Moran et al. (2021) point out some differences like the position of the center of mass during take-off, where vertical jumps show practically no displacement of the center of mass in a horizontal direction, but a vertical displacement of the center of mass was comparable between both types of jump, meaning that there are both the horizontal and vertical component of horizontal jumps, whereas vertical jumps possess a vertical component only. Given this, the authors conclude that horizontal jumps are more effective in enhancing horizontal performance but are no less effective than vertical jumps at enhancing vertical performance. Other significant difference is that horizontal jumps display shorter ground contact times, higher vertical ground reaction forces, greater limb stiffness and generally higher muscle activation in the rectus femoris, biceps femoris and gastrocnemius compared to vertical jumps, so coaches should consider this information when planning any type of jump training (Moran, et al., 2021).

Sprinting

After jumping, the second most common assessment performed was sprint time, from five to 30 meters, evaluated in 21 articles. Results varied from

no changes (Büsch, et al., 2015; Van Den Tillaar, Roaas. & Oranchuk, 2020) to improvements of 22.58% (Hammami, et al., 2020a). Directly related to sprinting is repeated sprint ability, which was assessed in 10 articles, and registered improvements between 1.56% (Cherif, et al., 2012) and 15.77% (Hammami, et al., 2020a).

It is curious to see that the two studies (Büsch, et al., 2015; Cherif, et al., 2012) that reported the poorest results in jumping also had the poorest results in sprinting, and that might be due to the neuromuscular and biomechanical similarities between jumping and sprinting (Gheller, Kons, Pupo, & Detanico, 2022; Markovic & Mikulic, 2010; Marques & Izquierdo, 2014; Pruyn, Watsford, & Murphy, 2014). The results of Büsch et al. (2015) might be due to the fact that some of the exercises were performed on unstable surfaces, as already mentioned before, and the lack of improvements in sprinting in the study by Cherif et al. (2012) might be due to the fact that only drop jumps were performed in the intervention, although that explanation does not make as much sense when trying to explain the decrease in jumping performance. The best results, from the study of Hammami et al. (2020a), might be explained by the fact that the PT intervention was combined with sprints, or by the fact that some part of the intervention was performed on sand (Markovic & Mikulic, 2010), and the group that did it was the one with better results in sprinting, although that was not the case in some other parameters.

Plyometrics target the stretch-shortening cycle (SSC), which involves rapid muscle stretching and contraction. Through neuromuscular adaptations, such as increased motor unit recruitment and improved intermuscular coordination, plyometric training enhances muscle power and rate of force development (RFD) and, biomechanically, it improves joint stiffness, extension during takeoff, and landing mechanics, optimizing energy transfer and, consequently, better sprinting performance (Oxfeldt, Overgaard, Hvid & Dalgas, 2019). Sprinting is a multidimensional movement skill that requires an explosive concentric and SSC force production of a number of lower-limb muscles, so it is expected that sprint performance benefits from PT (Markovic & Mikulic, 2010). It is important to note that it has been suggested that the greatest effects of PT on sprinting performance occur in the acceleration phase, since the velocity of muscle action in bounding plyometric exercises is closer to the velocities of muscle action in the acceleration phase of the sprint (Markovic & Mikulic, 2010; Saéz-Saez de Villarreal, Requena & Cronin, 2012).

Change of direction

This systematic scoping review includes 16 articles that evaluated COD, repeated COD, or used

tests like the T-test or Illinois test (or some variations of those) that are commonly said to evaluate agility, although the definition of agility may make it impossible to measure. However, that goes beyond the scope of this article, and we will use the definition utilized by the authors of the articles.

From all those tests, we registered results that varied from marginal gains of less than 1% (Iacono, et al., 2017; Karadenizli, 2015) to improvements of 14.5% (Hammami, et al., 2019). These positive results might be due to factors such as the development of force and high-power output, and the ability to efficiently use the SSC in ballistic movements, decreasing ground-reaction times through an increase in muscle-force output and movement efficiency (Asadi, et al., 2016; Markovic & Mikulic, 2010). Another potential mechanism that supports the use of PT to improve COD is that the pre-stretch of the muscles may enhance the concentric contraction due to neural potentiation, allowing the recruitment of a greater number of motor units, with a larger effect at increasing velocities (Falch, et al., 2020). Some of the previous authors (Falch, et al., 2020; Markovic & Mikulic, 2010) highlighted the important difference between force-velocity COD ($>90^\circ$) and velocity-oriented COD ($<90^\circ$), stating that PT has been shown to be beneficial in improving both but, especially in the case of velocity-oriented COD (with small angles), one of the benefits of PT is that it allows to keep reactive strength as the main contributor to maintain velocity.

The studies with the poorest results (Iacono, et al., 2017; Karadenizli, 2015) both completed a total of just 20 sessions, but we do not know if that explains the weak results. Some better justifications might be the fact that the study of Iacono et al. (2017) has a considerably low volume and was conducted with athletes of a relatively high age (compared with the other studies), while the study by Karadenizli (2015) did not provide important information that would be useful to try to justify the results. Meanwhile, the results of Hammami et al. (2019) might be attributed to the previously mentioned factors.

Strength

There were 12 articles doing some type of strength test. However, in this analysis, we will only mention the results from squat (and its variations) and bench press tests, since they were the most common strength assessments performed. The athletes saw their squat improving from 2.35% in the bilateral squat to 49.88% in the quarter squat, both in the same study (Falch, et al., 2022), and their bench press improved between 15.9% (Aloui, et al., 2021) and 30.3% (Hermassi, et al., 2019).

Regarding the study with the better squat results (Falch, et al., 2022), it is important to note that it is relevant to measure squat results with different

amplitudes, as squats with shallow amplitudes might have better transfer to some court performance markers, and the almost 50% increase in the quarter squat is a great improvement to consider.

Regarding the bench press improvements, it is important to note that the study with the poorest results (Aloui, et al., 2021) has only performed elastic-banded plyometric push-ups in their intervention, while the group with the better results (Hermassi, et al., 2019) have not done any upper-body plyometric exercises and did weight training and other exercises together with their plyometric intervention, which may be a better justification for the registered improvements in the bench press.

Ball throwing velocity

Ten articles measured ball throwing velocity, whether with a handball (with standing, jumping, or running shots) or with a medicine ball. Handball throwing velocity varied from negative results (Dahl & Van Den Tillaar, 2021; Soto Garcia, et al., 2022) to increases of 44% (Hermassi, et al., 2019), and medicine ball throwing velocity varied from negative results (Soto Garcia, et al., 2022) to improvements of 41.18% (Hermassi, et al., 2019).

As already mentioned in the outcomes table, the exercises implemented in the study by Dahl and Van Den Tillaar (2021) were not particularly well suited to the tests that they utilized, and the exercises in the study by Soto Garcia et al. (2022) were done with self-adjusted loads, so that might explain the weak results in both. In contrast, the study by Hermassi et al. (2019) utilized a variety of exercises and training modalities, so it is hard to attribute the good results to one particular factor.

Power

There were nine articles evaluating power in many different ways. The lowest improvement was 3.8% (Spieszny & Zubik, 2018), and the highest was 27.4% (Chelly, et al., 2014). Seven out of the nine studies evaluated anaerobic power, mainly with the Wingate test, and the highest registered improvement (27.4%) pertains to the upper body peak power in the cycle-ergometer test. As there were many ways to measure power in its different forms and regarding different body parts, it is hard to attribute a cause to the results. However, in their article that researched the effects of PT on anaerobic power, (Luebbbers, et al., 2003) suggested that the increases in power following PT could be due to increases in muscle fiber size, as improvements in muscle force production have been associated with increases in muscle fiber size and plyometrics can increase both type I and type II fibers, as well as increased motor unit functioning, since neuromuscular adaptations like increased inhibition of antagonist muscles as well as better activation and

co-contraction of synergistic muscles may account for the improvements in power output.

Balance

Balance was evaluated in eight articles, mainly by the Y-balance and Stork tests, but other tests were also utilized. Balance results varied from negative (Pancar, et al., 2020) to improvements of 365.2% (Hammami, et al., 2020a). These results must be interpreted carefully, as the results in Pancar et al. (2020) were not well explained, and an improvement with a magnitude of 365.2% must always be looked at with caution, not to say with suspicion.

Maximal oxygen uptake (VO2max)

VO2max was measured in six articles, and increases varied from 3.99% (Hammami, et al., 2018b) to 9.2% (Hammami, et al., 2021). It is important to note that four out of the six articles implemented PT together with other training methods such as HIIT, sprint or COD training, so that must always be considered when interpreting the results. We could speculate that the positive results might be attributed to improvements in running economy that are common with PT, but improvements in running economy may occur independent of changes in VO2max (Barnes & Kilding, 2015; Saunders et al., 2006; Turner, Owings, & Schwane, 2003). In their study with low-level runners, Turner et al. (2003) emphasized that PT improved running economy without altering the indicators of the ability of muscles to return strain energy, explaining that the improvement might have occurred by way of a mechanism not involving storage and return of elastic energy, or it involved enhanced storage and return of elastic energy but in a way that could not be detected with the indirect measurements used. Alterations in running mechanics that allow for better coordination and timing of ground force application would offer a mechanism to improve running economy (Saunders, et al., 2006), so that might be another explanation for the benefits of PT. Given these inconclusive findings, one should be cautious when making the connection between PT and improved running economy and, consequently, a possible increase in VO2max.

Future research

Given the limitations found in this study, there is a need for future research in the following fields:

The recent study by Montoro-Bombú et al. (2023) provided great advancements regarding the concern raised by Ramirez-Campillo et al. (2021a) about the lack of adequate markers for intensity in plyometric exercises, citing power output, reactive strength, rate of force development (RFD), ground reaction forces, stiffness, and reactive jump height as some markers to take into account while measuring PT intensity. However, Montoro-Bombú et

al. (2023) recognized that it is difficult to evaluate these parameters in a team sport context or in an environment where there are no financial resources to acquire the necessary equipment to obtain those parameters. Given that, sports scientists should strive to find ways to better evaluate plyometric intensity in these contexts, despite all the limitations and difficulties that it might entail.

About periodization, the sports science community should strive to reach a consensus regarding the definition of periodization, and always take that same definition into account while conducting future research on it. However, as noted by Hornsby et al. (2020), past research should never be disregarded, and should always be considered while trying to evolve it. Nevertheless, the aforementioned concerns (Afonso, et al., 2017, 2019; Kiely, 2012, 2018) that were raised should also be considered, and only by merging together all the information about this topic can better recommendations be provided.

Given that tapering protocols can be difficult to implement in a team sport context (Vachon, et al., 2021), it might not be easy to conduct many studies about it. However, more studies about tapering protocols in PT can and should be done, in order to enrich the findings by Ramirez-Campillo et al. (2021b).

Since coaches implement a vast number of plyometric exercises (Weldon, et al., 2020, 2022), it could be studied if there is a need to include all these different exercises in training programs, or if there are any particular exercises that are more efficient than others in improving physical markers (e.g., drop jumps vs depth jumps vs CMJ vs hurdle jumps vs hops vs bounds). Given that the time dedicated to improving the physical characteristics of team sport athletes is limited, this kind of information would be very useful for coaches. Besides this, it would also be useful to gather more information about the influence of different force vectors and their effect on improving COD with plyometric exercises, given the conflicting findings by Asadi et al. (2016) and Kons et al. (2023).

Given the lack of evidence regarding an ideal volume of PT, more studies researching the effects of different numbers of total ground contacts per session (e.g., 50 vs 100 vs 200 vs 400) would be useful for coaches and practitioners.

As mentioned before, more studies about the effect of different rest intervals should be done, whether inter-set or intra-set.

Conclusions and practical applications

The conclusions drawn from the present review underscore a prevalent emphasis on the lower limb, accompanied by considerable heterogeneity in methodological aspects, such as exercise types, and challenges in accurately gauging exercise inten-

sity. Nonetheless, the overarching consensus points towards a discernible positive impact of plyometric training on strength and power-related indicators among handball players.

Based on the comprehensive insights gleaned from this systematic scoping review and the amassed literature, the following practical applications emerge as pertinent considerations:

Surface selection: Given the nature of handball being practiced on hard surfaces, plyometric training (PT) is best conducted on similar terrain. However, if specific adaptations achievable through PT on soft surfaces, such as maximal dynamic strength production, are desired, coaches may incorporate such surfaces strategically to achieve those effects.

Intensity guidance: Coaches should heed the intensity recommendations outlined by Montoro-Bombú et al. (2023) when designing their plyometric exercises. This involves carefully considering optimal parameters for maximum power output, reactive strength, rate of force development (RFD), ground reaction forces, stiffness, and reactive jump height.

Exercise selection: While more research on exercise efficiency is awaited, coaches can confidently integrate common plyometric exercises such as hurdle jumps, drop jumps, depth jumps, vertical jumps, horizontal jumps, hops, bounds, and upper-body plyometric exercises.

Repeated jumps emphasis: Building upon the findings by Makaruk et al. (2014), coaches may consider incorporating repeated jumps more frequently than single jumps, as they may offer reduced landing forces and bring potential benefits.

Unilateral emphasis: A blend of both bilateral and unilateral plyometric exercises can be included in training regimens. However, prioritizing unilateral exercises and allocating a significant portion of the program to them is recommended.

Multidirectional preparation: To simulate diverse scenarios prevalent in handball competition, coaches should integrate plyometric exercises across all planes of movement, ensuring athletes are well-prepared for the multifaceted demands of the sport.

Volume and rest management: As the evidence does not substantiate the advantages of higher-volume PT programs, coaches should structure sessions with a total ground contact count ranging between 50-100 per session. Customizable rest intervals, varying from 30 seconds to two minutes, can be introduced based on available training time.

Frequency and consistency: Considering the multifaceted commitments of team sport athletes and coaches, a recommended frequency of 2-3 PT sessions per week aligns well with the need for balanced training and ample recovery.

In summation, these derived practical applications offer a comprehensive roadmap for optimizing plyometric training within the context of handball, underpinned by the amalgamation of research findings and expert insights.

Following Table 4, a compilation of overarching recommendations is presented concerning the optimal surface type and recommended ground contact times for the incorporation of plyometric training. These insights are predominantly drawn from the comprehensive findings of recent research (Montoro-Bombú, et al., 2023):

Table 4. Practical applications of plyometric training for handball players

Hard surface	Soft surface
Recommended to be introduced after working on soft surfaces.	Longer contact times, slower reactivity
Associated with short ground contact times, and bouncing jumps with open knee joint angles	Associated with the production of maximal dynamic strength,
Allow shorter ground contact times, which guarantees better reactivity	Can be used for DJ when a greater emphasis on CMJ and jump height is sought and when short contact times are not required
Associated with the development of power, muscle stiffness and reactive strength	Can be used for rehabilitation
Ideal for jumps that require short contact times and are primarily based on fast bouncing	More adequate during the first developmental phase of sprint acceleration, where more work on high-force production at relatively low speeds is sought for
Longer contact times	Shorter contact times
Involve a countermovement and higher drop heights	More open knee and hip angles
Better for producing maximal dynamic strength	Better for the development of maximum power output production, RFD and reactive strength
Increases ground reaction forces and maximal eccentric force production	Less ground reaction forces
Can be combined with general or maximal strength work	Can be combined with power-oriented weight training work
Recommended exercises: depth landings, depth jumps, horizontal drop jumps, and jumping between high hurdles	Recommended exercises: tuck jumps, drop jumps, and jumping between medium hurdles

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**CHAPTER 4 - HIGH-INTENSITY INTERVAL
TRAINING PROGRAMS AND THEIR IMPACT ON
ENDURANCE PERFORMANCE IN HANDBALL
PLAYERS: A SYSTEMATIC REVIEW**

SCIENTIFIC ARTICLE 2

Henrique, J. R., Ramirez-Campillo, R., Fernandez, F. T. G., Castillo, D., Raya-González, J., Zmijewski, P., ... & Clemente, F. M. (2024). High-intensity interval training programs and their impact on endurance performance in handball players: A systematic review. *Biomedical Human Kinetics*, 16(1), 113-130.

High-intensity interval training programs and their impact on endurance performance in handball players: A systematic review

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Abstract

Study aim: This systematic review aimed to identify and analyze the available evidence about the effects of high-intensity interval training (HIIT) interventions on endurance performance in handball players.

Material and methods: The search for relevant literature was conducted across prominent databases, including PubMed, Scopus, SPORTDiscus, and Web of Science Core Collection. The eligibility criteria focused on healthy handball players, without restrictions on age, sex, or competitive level, who were exposed to HIIT interventions, either alone or in combination with other training methods. The methodological assessment employed the RoB2 and ROBINS scales. A screening process was executed, evaluating 434 titles, leading to the inclusion of 17 eligible studies in this systematic review, comprising a total of 369 participants.

Results: Most studies on HIIT in handball involved tier-two athletes (trained/developmental) and mostly men. The training frequency typically implemented was twice per week, with a duration between 4 and 12 weeks, with different types of HIIT. There was considerable variation in outcomes across the included studies, with most of them demonstrating a significant positive impact of HIIT on improving endurance performance when compared to controls.

Conclusion: In conclusion, the predominant focus of the overall analyzed studies was on the effects of different HIIT interventions in obtaining positive performance adaptations assessed by field-based tests in handball players.

Keywords: Team sports – Intermittent exercise – HIIT – Endurance – Handball

Introduction

During handball matches, players exhibit elevated heart rates (HR), oxygen uptake (VO₂), blood lactate levels, glycogen utilization, and lipid metabolism, highlighting the substantial aerobic and anaerobic demands of the sport [41, 54]. Although there are studies that claim that these attributes do or do not differentiate elite performance and are crucial to success [36, 39], prior studies have recommended the utilization of intermittent

exercise to improve the endurance performance of these players [22, 52].

While continuous and interval training has been utilized for years to enhance athletes' aerobic and anaerobic capacities [32, 43], it should be noted that these training modalities stimulate different physiological adaptations [21]. Remarkably, high-intensity interval training (HIIT) has shown to be effective in promoting adaptations in the anaerobic threshold, maximal oxygen uptake (VO_{2max}), and the ability to repeatedly perform high-intensity efforts [35]. Additionally, it offers the advantage of significantly reducing

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the time required to observe positive adaptations to training when compared to continuous training [34]. HIIT can elicit physiological responses that enhance the capacity for aerobic energy performance [23], and these improvements can be due to physiological factors, such as an increase in the number of mitochondria, and consequently, an increased $\text{VO}_{2\text{max}}$ and improved capacity for oxidative metabolism in skeletal [2]. However, there is still no consensus statement on how HIIT interventions have the potential to improve endurance performance in handball [23].

Prescription for HIIT consists of the manipulation of up to nine variables, which include the work interval intensity and duration, relief interval intensity and duration, exercise modality, number of repetitions, number of series, as well as the between-series recovery duration and intensity [9], and the manipulation of any of these variables can affect the physiological responses to HIIT [9]. Regarding protocol characterization, interval training is infinitely variable and there is a lack of standardization (both in the scientific literature and amongst practitioners) about the terminology used to describe different approaches [23], however, the most referenced forms of interval training are short and long intervals, repeated sprint training (RST), sprint interval training (SIT) and small sided games (SSGs) [10].

Although HIIT prescription has been recommended in the literature based on percentages of maximum HR, heart rate reserve (HRR), $\text{VO}_{2\text{max}}$, and VO_2 reserve [51], a previous study highlighted significant inter-individual variations in both relative mean and peak power [51]. Consequently, the cardiopulmonary or metabolic strain, along with the exercise stimuli, differs substantially among subjects [51]. The same authors proposed utilizing indicators such as lactate or ventilatory thresholds for a more effective prescription of interval training [51]. However, in situations characterized by limited resources or many athletes, as often encountered in team sports such as handball, alternative methods like maximal aerobic speed or anaerobic speed reserve are typically favored [51].

Given the limited understanding of how exercise intensity, duration, and frequency impact various physiological responses during interval training, this systematic review aims to offer a comprehensive perspective on the existing evidence concerning the effects of HIIT on endurance performance in handball players.

Methods

This systematic scoping review followed rigorously the guidelines outlined in the PRISMA 2020 framework [50] and the guidelines for reporting systematic reviews in sports sciences [44]. To ensure transparency and preclude bias, a detailed protocol for this review was meticulously registered on the Open Science Framework (OSF)

under the code “osf.io/2rjph” and DOI: 10.17605/OSF.IO/J9MEZ on September 08, 2023.

Eligibility criteria

This systematic scoping review only includes original articles in the form of full text that have been subjected to peer review. No restrictions were added to the language or date of publication. Following the PICOS (i.e., population, intervention/exposure, comparator, outcome, study design) approach, the eligibility criteria were as follows:

- (i) Population: handball players from any competitive level, age, or sex.
- (ii) Intervention: The review encompassed interventions involving HIIT and/or combined training, where the latter incorporates HIIT as a substantial component, comprising at least 50% of the total training intervention duration, as determined by the exposure time.
- (iii) Comparator: This systematic review focused exclusively on studies employing parallel study designs where the intervention group(s) received regular training only, i.e., they were exposed to standard in-field training. Additionally, active control groups were included, receiving specific training interventions that did not encompass high-intensity interval training, irrespective of whether these interventions were volume-equated. In cases of non-randomized studies, passive control groups were also considered for inclusion in the review.
- (iv) Outcomes: The primary outcomes considered for inclusion in this review are centered around measures of endurance performance which can be assessed using at least two time points (pre-post). These measures encompass but are not limited to, maximal oxygen uptake (whether measured directly or indirectly), anaerobic threshold, maximal aerobic speed, and performance in field-based maximal tests.
- (v) Study design: The scope of this systematic review was intentionally limited to encompass study designs that are parallel, whether or not they involve randomization.

Search strategy

During the search process, Boolean operators AND/OR were judiciously applied to combine keywords and synonyms across all fields to ensure comprehensive coverage. No filters were imposed to maximize the likelihood of identifying relevant studies. A thorough exploration of keywords and synonyms was conducted, employing various combinations to facilitate the most exhaustive search possible.

[Title/Abstract] (Handball* OR “Hand-ball”*)

AND

[All fields] (“high-intensity interval training” OR “interval training” OR “HIIT” OR “intermittent training” OR “resistance interval training” OR “circuit training”)

Table 1. Full search strategy for each database

Database	Specificities of the databases	Search strategy	Titles retrieved (n)
PubMed	None to report	(Handball*[Title/Abstract] OR “Hand-ball*”[Title/Abstract]) AND (“high-intensity interval training” OR “interval training” OR “HIIT” OR “intermittent training” OR “resistance interval training” OR “circuit training”)	22
SportDiscus		TI (Handball* OR “Hand-ball*”) AND TX (“high-intensity interval training” OR “interval training” OR “HIIT” OR “intermittent training” OR “resistance interval training” OR “circuit training”) AND AB (Handball* OR “Hand-ball*”) AND TX (“high-intensity interval training” OR “interval training” OR “HIIT” OR “intermittent training” OR “resistance interval training” OR “circuit training”)	86 + 104
Scopus	Search for title and abstract also includes keywords	(TITLE-ABS-KEY (handball* OR “Hand-ball*”) AND ALL (“high-intensity interval training” OR “interval training” OR “HIIT” OR “intermittent training” OR “resistance interval training” OR “circuit training”))	208
Web of Science	Search for title and abstract also includes keywords and its designated “topic”	Handball* OR “Hand-ball*” (Topic) and “high-intensity interval training” OR “interval training” OR “HIIT” OR “intermittent training” OR “resistance interval training” OR “circuit training” (All Fields)	34

The full search strategy can be observed in the following table 1.

Information sources

On September 08, 2023, the authors FMC and JH initiated the search for pertinent publications across electronic databases, including PubMed, Scopus, SPORTDiscus, and the Web of Science core collection. In addition to these database searches, the review process encompassed the following supplementary methodologies: (i) Manual searches: A thorough examination of the reference lists of included studies was conducted to identify potentially relevant titles; and (ii) Snowballing citation tracking within the Web of Science platform to trace citations and identify relevant sources.

Selection process

The screening process was executed by two authors, JH and FMC, who independently assessed the retrieved records based on their titles and abstracts. Subsequently, the same authors independently evaluated the full texts of the selected studies. Any discrepancies or disagreements that arose between these two authors during the screening process were resolved through joint reanalysis and discussion.

In cases where a consensus could not be reached, a third author, RMS, was consulted to make the final decision. As

required, all co-authors were involved in providing their input and opinions to address any uncertainties that arose during the selection of studies, thus contributing to the final decision-making process.

To manage the records and ensure the removal of duplicates, the team employed EndNote™ 20.4 software, developed by Clarivate™. Duplicate entries were eliminated using a combination of automated and manual methods as needed.

Extraction of data

A data extraction sheet was employed to assess inclusion requirements and facilitate the systematic data extraction process. This sheet was adapted from the template used by the Cochrane Consumers and Communication Review Group [42]. To ensure its effectiveness, a pilot testing phase was carried out on a randomly selected sample comprising 10% of the studies.

This data extraction process was conducted by two authors, JH and FMC, who were responsible for evaluating the included studies. Any full-text articles that were excluded during this process were meticulously documented along with the specific reasons for their exclusion. The recorded data were organized and managed using a structured form created in Microsoft Excel, developed by Microsoft Corporation in Redmond, WA, USA. This form

served as a central repository for the collected information and facilitated subsequent analysis and synthesis of the data.

Data items

The data collection process, conducted by JH and FMC, involved gathering comprehensive information and details about the included studies, which encompassed but were not limited to, the following key elements: authors' identities, the publication year, the study design, the nature of the treatment employed, any existing control group, the implementation of randomization, strategies for blinding (if applicable, instances of injuries observed, citation specifics, the country where data collection occurred, sources of funding, and disclosures of competing interests.

Context-related information included the timing within the season (e.g., off-season, pre-season, in-season). Participant-related information included the number of participants, sex, age, the competitive level (while using the Participant Classification Framework) [35], body mass, height, high-intensity interval training experience, and sport practiced (e.g., handball, para-handball, beach handball).

Intervention-related information included the number of weeks, sessions per week, duration of each session, the total number of sessions within the entire program, and the rest intervals between HIIT sessions. The intensity of the training, as well as any methods used for quantification, was also documented. Moreover, the type of surface on which the training occurred, such as turf, sand, or concrete, was noted. The training regimen, including sets, repetitions, and rest intervals between sets and repetitions, was recorded.

Furthermore, information related to the type of running-based HIIT, such as short or long sprints, repeated sprint training, or sprint interval training, along with data on distance covered, pace, and changes of direction per set, was collected. Additional aspects such as rest intervals between sets, repetitions, and training sessions, as well as details about the training period, tapering strategies, novel program aspects, limitations, considerations, and the potential combination of HIIT with other training methods, were also documented for a comprehensive analysis of the interventions.

Outcomes-related information encompassed various parameters associated with endurance performance. These measures included the following aspects: (i) the direct or indirect assessment of $\text{VO}_{2\text{max}}$; (ii) the direct or indirect evaluation of maximal aerobic speed (MAS); (iii) the quantification of distance covered during endurance field-based assessments; (iv) the duration of endurance before exhaustion was reached in a specific test; or (v) the determination of the ventilatory threshold.

Study risk of bias assessment

Utilizing Cochrane's Risk of Bias tool, version 2 (RoB 2), parallel randomized studies underwent comprehensive bias assessment across five domains: randomization process, deviations from intended interventions (inclusive of intention-to-treat analysis), missing outcome data, measurement of outcomes, and selection of the reported results. Conversely, non-randomized studies were subject to a thorough evaluation of bias across seven domains, as outlined by Cochrane's Risk of Bias in Non-Randomized Studies of Interventions (ROBINS-I). These domains encompassed confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement, and selection of the reported results.

The assessment of bias occurred at both the outcome and study levels, with the most unfavorable scenario per study being reported. In cases where a pre-registered protocol was unavailable, the risk of bias associated with the selection of the reported results was considered to be of at least moderate concern (RoB 2) or moderate risk (ROBINS-I). Two authors, JH and FMC, conducted independent bias assessments, with a third author, RMS, available as an arbitrator whenever necessary. The collective summaries of the risk of bias evaluations were subsequently presented according to the primary outcome measures.

Results

Study identification and selection

The search of databases identified a total of 434 titles. These studies were then exported to reference manager software (EndNoteTM X9, Clarivate Analytics, Philadelphia, PA, USA). Duplicates (175 references) were subsequently removed either automatically or manually. The remaining 259 articles were screened for their relevance based on titles and abstracts, resulting in the removal of a further 183 studies. The full texts of the remaining 76 articles were examined diligently; 61 were rejected, as they did not satisfy the relevant criteria (e.g., HIIT interventions in soccer or other sports), and they were excluded due to several reasons, as described in the PRISMA flow diagram (see Figure 1). Six studies were retrieved by experts, and 4 were included. The 17 studies included in this systematic review provided mean and standard deviation for pre – and post-intervention data for at least one main outcome.

Study characteristics

The characteristics of the 17 studies included in this systematic review and the details of the HIIT programs can be found in Table 2. The included randomized-controlled

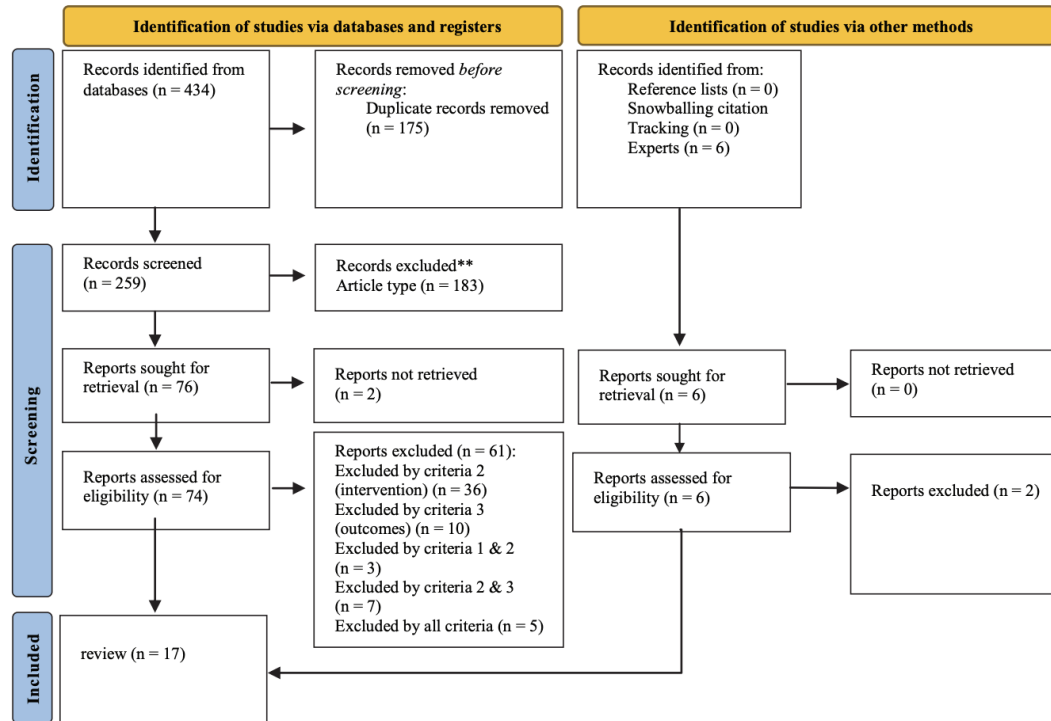


Figure 1. PRISMA 2020 flow diagram

studies involved 14 experimental groups with 158 participants and 10 control groups with 119 participants. The non-randomized controlled studies involved 6 groups and 56 participants, and the quasi-experimental studies involved 2 groups and 36 participants.

Most of the included studies (~76%) focused on tier 2 competitive-level players, representing those classified as trained/developmental with a local-level representation. Regarding the age of participants, 8 studies included individuals above 18 years old, indicating that the remaining nine focused on youth participants. Twelve of the studies had male participants, 4 had women participants, and 1 had both men and women. In terms of study design, the most common were randomized controlled trials (n = 12), followed by non-randomized controlled trials (n = 3) and quasi-experimental studies (n = 2). The most employed assessment tests included some form of shuttle run/sprint (n = 11), the Yo-Yo intermittent recovery test level 1 (n = 5), and the 30-15 intermittent fitness test (n = 4). The most prevalent outcomes measured were best, mean, or total times during sprints to calculate repeated sprint ability (RSA) (n=8) the distance covered in various tests, mostly 30-15IFT and Yo-Yo intermittent recovery test

level (n = 6), MAS, and indirect measurement of $\text{VO}_{2\text{max}}$ (both n = 4).

The interventions included in this systematic review lasted between 4 and 12 weeks, with 50% lasting 8 weeks. The weekly frequency of the intervention sessions varied from 2 to 4, with most of them (65%) implementing a frequency of 2 sessions per week.

Table 3 presents a summary of the methodological characteristics of the interventions included in this systematic review. The most common formats used were short intervals and small-sided games (both n = 6), followed by long intervals and high-intensity resistance training (both n = 2). The remaining formats (sprint interval training [SIT], repeated sprint training [RST], Tabata, and Mixed) were employed in only one study each. Regarding the number of sets/ reps performed in the interventions, it varied from 1 to 12 in sets and 4 to 22 in reps. In the HIIT interventions, the work duration ranged mostly between 5 and 30 seconds, utilized in 11 studies, with rest periods in the same interval being used in a similar number of studies. Regarding SSGs, only one study utilized a 2vs2 playing format, with the majority being 3vs3 and 4vs4, in pitches with dimensions ranging between 20×10m and

Table 2. Characteristics of the included studies and outcomes extracted

Study	N	Mean age	Sex	Competitive level (Tier)	Design	Outcomes	Tests used in the original studies	Measures extracted from the tests in the original studies
Alonso-Fernández et al. [1]	EG: 7 CG: 7	15.2 ± 0.6	F	2	RCT	RSA; Estimated VO _{2max}	RSA: 4 linear sprints with COD Estimated VO _{2max} : 20m shuttle run	RSA: Total time during the sprints (s) Estimated VO _{2max} : ml/kg/min
Balasubramania et al. [3]	EG: 8 CG: 8	22.12 ± 3.22	M	2	RCT	AP	AP: YYIRTL2	AP: distance (m)
Buchheit et al. [11]	HIT: 15 HBT: 17	15.5 ± 0.9	M+F	2	RCT	AP; RSA	AP: 30–15 IFT RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s/14s rest between sprints	AP: V _{IFT} (km/h) RSA: best and mean sprint time (s)
Buchheit et al. [12]	S/A: 7 SIT: 7	15.8 ± 0.9	M	2	nRCT	AP; RSA	AP: 30–15 IFT RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s/14s rest between sprints	AP: V _{IFT} (km/h) RSA: best and mean sprint time (s)
Chittibabu et al. [13]	EG: 15 CG: 15	23.15 ± 3.0	M	2	RCT	Estimated VO _{2max}	Estimated VO _{2max} : multistage (20m shuttle run)	Estimated VO _{2max} : ml/kg/min
Chittibabu et al. [14]	EG: 8 CG: 8	22.12	M	2	RCT	RSA; Estimated VO _{2max}	RSA: 7×30m sprints departing every 25s Estimated VO _{2max} : YYIRTL2	RSA: total time (s) Estimated VO _{2max} : ml/kg/min
Curliuanu et al. [16]	T: 9 SI: 9	18–23	F	3	nRCT	Aerobic endurance	Cooper 12-min	distance (m)
Iacono et al. [30]	SI: 9 SSGs: 9	25.6 ± 0.5	M	3	RCT	AP	AP: YYIRTL1	AP: distance (m)
Florin et al. [19]	18	26.94 ± 3.78	M	3	Q-E	MAS	MAS: 30–15 IFT	MAS: km/h
Gaamouri et al. [20]	EG: 15 CG: 13	16.5 ± 0.4	M	2	RCT	RSA; MAS	RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s MAS: 20m shuttle run	RSA: best and mean sprint time (s) MAS: km/h
Hammami et al. [24]	EG: 17 CG: 15	16.6	M	2	RCT	RSA; MAS; Estimated VO _{2max}	RSA: Repeated Sprint T-test Estimated VO _{2max} and MAS: 20m shuttle run	RSA: best, mean and total time (s) Estimated VO _{2max} : ml/kg/min MAS: km/h
Hermassi et al. [27]	EG: 15 CG: 15	17.0 ± 1.2	M	2	RCT	RSA; MAS	RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s MAS: YYIRTL1	RSA: best and total time (s) MAS: m/s
Hermassi et al. [28]	EG: 10 CG: 9	18.5 ± 0.85	M	2	RCT	AP	AP: YYIRTL1	AP: distance (m)

Table 2. Cont.

Study	N	Mean age	Sex	Competitive level (Tier)	Design	Outcomes	Tests used in the original studies	Measures extracted from the tests in the original studies
Bhakti et al. [29]	18	N. D.	M	N. D.	Q-E	Estimated VO_{2max}	Estimated VO_{2max} ; 3000m run	VO_{2max} ; N. D.
Jurišić et al. [31]	SI: 12 SSGs: 12	16.13	F	2	nRCT	AP	AP: YYIRTL1	AP: distance (m)
Mikalonytė et al. [37]	EG: 12 CG: 12	16.2 ± 1.5	F	2	RCT	AP	AP: YYIRTL1	AP: distance (m)
Viaño-Santamarinas et al. [52]	SI: 10 LI: 8	22.7 ± 3.9	M	2	RCT	AP; RSA	AP: 30–15 IFT RSA: 6 reps of 2×15m all-out shuttle sprints departing every 20s	AP: V_{IFT} (km/h) RSA: best, mean and total time (s)

Note: EG: experimental group; CG: control group; HIT: high-intensity interval training group; HBT: handball-based training group; S/A: sprint and agility group; SIT: sprint interval training; T: tabata; SSGs: small-sided games; SI: short intervals; LI: long intervals; RCT: randomized controlled trial; Q-E: quasi-experimental; RSA: repeated sprint ability; VO_{2max} : maximal oxygen uptake; AP: aerobic performance assessed from field-based tests; MAS: maximal aerobic speed; COD: change of direction; YYIRT: yoyo intermittent recovery test; 30–15IFT: 30–15 intermittent fitness test; V_{IFT} : maximal velocity at 30–15IFT.

40×20m. Regarding the training regimen, the studies utilizing SSGs employed 4 to 12 games per session, lasting between 2 min 25s and 10 min.

Study risk of bias assessment

Tables 4 and 5 provide an assessment of the risk of bias for the randomized studies using the RoB2 instrument. The tables focus on studies that examined endurance performance and VO_{2max} . All of the included studies that analyzed endurance performance had an overall high risk of bias, which was primarily influenced by concerns in dimensions dealing with the selection of the reported results. The main reason for these concerns was the absence of information regarding pre-specified analyses, making it unclear whether the reported results were selectively chosen from a larger set of outcomes.

The other dimension that brought some concerns was dimension 1, which relates to the lack of information provided about the randomization techniques and allocation concealment. Specifically, 10 out of 11 articles analyzed did not provide sufficient details regarding these critical aspects of the study design, and the study by Buchheit et al. [11] had a high risk for this particular dimension. The other dimensions had a low risk of bias but, overall, the assessment of risk of bias indicates that all of the included studies had limitations in key methodological aspects, particularly in the randomization and selection of the reported results. These limitations should be taken into consideration when interpreting the findings and assessing the overall quality of the evidence presented in this systematic review.

Similarly, the assessment of the risk of bias for the four randomized studies that examined VO_{2max} revealed an overall high risk of bias, consistent with the concerns identified for the endurance performance outcome.

Table 6 provides an assessment of the risk of bias for the non-randomized studies using the ROBINS-I instrument. Two [12, 16] of the three studies presented an overall moderate risk of bias, due to deviations from intended interventions, while the study by Jurišić et al. [31] had an overall low risk of bias, with low risk in all fields.

Table 7 provides an assessment of the risk of bias for the quasi-experimental studies using the Downs and Black modified checklist. The two quasi-experimental studies had an overall low-quality score, which indicates that both studies had poor methodological quality.

Summary of the main results

Tables 8, 9, and 10 provide a summary of the main findings regarding the adaptations induced by HIIT and SSG-based interventions on field-based test outcomes. Studies that measured time in shuttle-sprint tests (the most frequently employed test) have ranged from increases in sprint time of 0.69% [12] to decreases of 7.22% [1].

Table 3. Characteristics of the HIIT programs included

Study	HIIT format	Duration (w)	d/w	Total sessions	Work duration or distance	Work intensity	Relief duration	Relief intensity	Series	Reps	Rest between sets (duration)	Rest between sets (intensity)	SSG format	SSG pitch dimension	SSG area per player (m ²)
Alonso-Fernández et al. [1]	SI	8	2	16	20s	>85% HRmax	10s	–	8	–	2min	–	–	–	–
Balasubramania et al. [3]	SSGs	6	3	18	4min	90–95% HRmax	4min	Active	–	4	–	–	4×4	40×20m	–
Buchheit et al. [11]	SI	9	2	17	15s	90–100 % V _{IFT}	15s	Passive	1–2	5	–	–	–	–	–
Buchheit et al. [12]	SIT	4	2	8	30s	All-out	2min	Passive	–	3–5	–	–	–	–	–
Chiribabu et al. [13]	RST	8	3	24	30m	–	15s	Passive	3	10	150s	–	–	–	–
Chiribabu et al. [14]	SSGs	8	3	24	4min	90–95% HRmax	4min	Active	–	4	–	–	4×4	40×20m	–
Curitiani et al. [16]	Tabata + LI	T: 6 LI: 8	4	T: 24 LI: 32	T: 20s LI: 45s	T: All-out LI: N.D.	T: 10s LI: 30s	–	T: 2 LI: 5	–	–	–	–	–	–
Iacono et al. [30]	SI + SSGs	8	2	16	SI: 15s SSGs: 2m25s to 3m10s	SI: 90–95% MAS	SI: 15s	Passive	SI: 12 SSGs: 5	–	SSGs: 1min	Passive	3×3	20×20m	–
Florin et al. [19]	Mixed	8	2–3	20	10s–5min	80–110 % V _{IFT}	10–30s	Passive	2–6	–	3–7min	Active	–	–	–
Gaouri et al. [20]	HIIT	8	2	16	5s	130% MAS	10s	–	8	2	3–5min	–	–	–	–
Hammami et al. [24]	HIIT	8	2	16	5s	130% MAS	10s	–	8	2	3–5min	–	–	–	–
Hermassi et al. [27]	SI	7	2	14	10–20s	110–130% MAS	10–20s	–	1–4	5–10	3min	–	–	–	–
Hermassi et al. [28]	–	12	2	24	–	All-out	–	–	2	–	3min	–	–	–	–
Bhakti et al. [29]	–	5	4	18	–	–	–	–	–	–	–	–	–	–	–
Jurišić et al. [31]	SI + SSGs	8	2	16	SI: 15s SSGs: 2m25s to 3m10s	SI: 90–95% MAS	SI: 15s	SI: Active	SI: 2 SSGs: 5	–	SI: 3min SSGs: 1min	SI: N.D. SSGs: Passive	3×3	20×20m	–
Mikalonyé et al. [37]	SSGs	10	2	20	10min	–	–	–	3	–	1min	–	2×2, 3×3, 4×4	20×10m, 20×20m	40.7, 54.3
Viano-Santasmarias et al. [52]	SI + LI	6	2	12	SI: 10s LI: 3min	SI: 95% V _{IFT} LI: 85% V _{IFT}	SI: 10s LI: 3min	Passive	SI: 2 LI: 5	SI: 22 LI: 5	SI: 5min	SI: Passive	–	–	–

Note: SSGs: small-sided games; SI: short intervals; LI: long intervals; SIT: sprint interval training; RST: repeated sprint training; HIIT: high-intensity resistance training; w: weeks; d: days; T: tabata; HRmax: maximal heart rate; V_{IFT}: maximal velocity at 30–15IFT; MAS: maximal aerobic speed.

Table 4. Assessment of risk of bias for randomized studies for outcome VO_{2max}

Study	D1	D2	D3	D4	D5	Overall
Alonso-Fernández et al. [1]	!	+	+	+	-	-
Chittibabu et al. [13]	!	+	+	+	-	-
Chittibabu et al. [14]	!	+	+	+	-	-
Hammami et al. [24]	!	+	+	+	-	-

Table 5. Assessment of risk of bias for randomized studies for outcome Endurance performance

Study	D1	D2	D3	D4	D5	Overall
Alonso-Fernández et al. [1]	!	+	+	+	-	-
Balasubramanian & Chittibabu [3]	!	+	+	+	-	-
Buchheit et al. [11]	-	+	+	+	-	-
Chittibabu et al. [14]	!	+	+	+	-	-
Iacono et al. [30]	!	+	+	+	-	-
Gaamouri et al. [20]	!	+	+	+	-	-
Hammami et al. [24]	!	+	+	+	-	-
Hermassi et al. [27]	!	+	+	+	-	-
Hermassi et al. [28]	!	+	+	+	-	-
Mikalonytė et al. [37]	!	+	+	+	-	-
Viaño-Santamarinas et al. [52]	!	+	+	+	-	-

Studies utilizing the Yo-Yo Intermittent Recovery Test Level 1 demonstrated decreases of 10.67% [37] to improvements of 69.2% [28] in distances achieved, and improvements ranging from 3.72% (12) to 9.5% [19] in the velocity in the 30-15 Intermittent Fitness Test. Moreover, when analyzing studies that measured VO_{2max} , the results have shown increases between 6.9% to 137.6% [29], however, this last value should be interpreted with caution, as the study showed a low-quality score and did not specify how they evaluated the athletes.

Discussion

This systematic review aimed to analyze the available evidence regarding the effects of HIIT interventions on endurance performance in handball players. The impact on endurance performance was mainly assessed by

evaluating the effects on parameters like VO_{2max} , maximal aerobic speed, and accumulated distances covered in progressive field-based tests. In general, a positive effect was observed on aerobic performance in the subjects that performed a HIIT intervention. In the randomized controlled trials, except the studies by Buchheit et al. [11, 12] and Mikalonytė et al. [37], there was a significant inter-group benefit favorable to the HIIT intervention groups compared to the control groups. All 4 studies [16, 30, 31, 52] with only experimental groups recorded positive effects in both interventions, and the two quasi-experimental studies [19, 29] also recorded improvements.

Effects of high-intensity interval training on handball players' maximal oxygen uptake

Only four studies from this systematic review estimated VO_{2max} through field-based tests, three of them RCTs [1, 13, 14], while the other one [29] was a quasi-

Table 6. Assessment of risk of bias for randomized studies

Study	Bias due to confounding	Bias in selection of participants in the study	Bias in classification of interventions	Bias due to deviations from intended interventions	Bias due to missing data	Bias in measurement of outcomes	Bias in selection of the reported result	Overall Bias
Buchheit et al. [12]	Low	Low	Low	Moderate	Low	Low	Low	Moderate
Curijanu et al. [16]	Low	Low	Low	Moderate	Low	Low	Low	Moderate
Jurišić et al. [31]	Low	Low	Low	Low	Low	Low	Low	Low

Table 7. Assessment of risk of bias for quasi-experimental studies

Author, year	Reporting (n = 10)	External validity (n = 3)	Internal validity – bias (n = 7)	Internal validity – confounding (n = 6)	Power (n = 1)	Total quality score (n = 27)
Florin et al. [19]	6	0	3	2	0	11
Bhakti [29]	5	0	3	2	0	10

experimental study. Regarding the outcomes, there was considerably greater amplitude in VO_{2max} improvements compared to the results of other parameters. The VO_{2max} results have shown increases between 6.9% [1] to 137.6% [29]. However, the results presented by Bhakti [29] should be interpreted carefully, as the study presented a low quality, had no control group, and there was no information about how the outcome was evaluated. If that study is excluded, the VO_{2max} improvements of the remaining studies presented considerably lower variability, with the experimental groups increasing their VO_{2max} between 6.9% [1] and 9.4% [24], which are much more homogeneous values, and presenting significant increases compared to their control group counterparts. However, other studies also have considerable limitations, given that the study by Chittibabu et al. [13] does not provide the results of the control group, and the other does not provide the pre-post values, only referencing their final results [14].

The reduced number of studies that evaluated the impact of HIIT programs on handball athletes' VO_{2max} has shown similar results to many studies that were included in several systematic reviews and meta-analyses that have studied the impact of different forms of HIIT on VO_{2max} in different populations, including athletes [38, 40, 45, 48, 55]. Regarding acute physiological responses, High-Intensity Interval Training (HIIT) protocols typically exhibit elevated cardiovascular indicators. This includes heightened mean and peak heart rates (HRmean, HRpeak), increased mean oxygen consumption (VO_{2mean}) and maximum oxygen consumption (VO_{2max}), elevated blood lactate and alpha-amylase concentration, augmented ventilation, and carbon dioxide output. Additionally, there's an improved oxygen utilization in the muscle [18, 25]. These responses have been observed across diverse populations and age groups.

HIIT sessions might trigger cardiocirculatory adaptation via cardiovascular adjustments occurring specifically during the recovery periods, and the peripheral and central chronic adaptations generated by different HIIT types are dependent on the metabolic and cardiorespiratory acute responses induced by the training sessions, as there are differences among the acute responses of different forms of HIIT [9, 15].

According to several studies that have analyzed the physiological mechanisms that drive adaptations in maximal oxygen uptake, these improvements might be attributed to increased stroke volume, maximal cardiac output, maximal arteriovenous oxygen difference, plasma volume, left ventricular mass, capillary density, blood flow, maximal citrate synthase activity, skeletal-muscle oxidative enzyme capacity, and mitochondrial content, increased capacity of the central nervous system to recruit motor units and increased red blood cell volume and hemoglobin mass, resulting in higher oxygen carrying capacity [45].

Table 8. Summary of main results for experimental studies with control group

Study	Intervention	Sub-group	Total sessions	Tier	Randomized	N	Outcome	Before Mean $\pm$ SD	After Mean $\pm$ SD	Before-After ($\Delta\%$)
Alonso-Fernández et al. [4]	HIIT	SI	16	2	Yes	7	Total time during sprints (s) Estimated $\dot{V}O_{2max}$ (ml/kg/min) at 20-m shuttle run test	RSA: 16.76 $\pm$ 0.72 $\dot{V}O_{2max}$: 43.96 $\pm$ 2.8	RSA: 15.55 $\pm$ 0.55 $\dot{V}O_{2max}$: 46.68 $\pm$ 2.60	RSA: -7.22* $\dot{V}O_{2max}$: 6.19*
Alonso-Fernández et al. [4]	CG	Warm-up	16	2	Yes	7	Total time during sprints (s) Estimated $\dot{V}O_{2max}$ (ml/kg/min) at 20-m shuttle run test	RSA: 17.74 $\pm$ 1.24 $\dot{V}O_{2max}$: 42.73 $\pm$ 6.53	RSA: 17.46 $\pm$ 1.31 $\dot{V}O_{2max}$: 43.27 $\pm$ 6.31	RSA: -1.58 $\dot{V}O_{2max}$: 1.26
Balasubramania et al. [3]	SSGs	4x4	18	2	Yes	8	Distance (m) at YYIRTL2	-	-	4.56
Balasubramania et al. [3]	CG	CG	18	2	Yes	8	Distance (m) at YYIRTL2	-	-	-
Buchheit et al. [11]	HIIT	SI	17	2	Yes	15	Velocity (km/h) at 30-15IFT Best sprint time (s) at 6 reps of 2x15m all-out shuttle sprints	AP: 17.9 $\pm$ 1.8 RSA ₆ : 6.27 $\pm$ 0.42	AP: 18.9 $\pm$ 1.3 RSA ₆ : 6.05 $\pm$ 0.37	AP: 5.59* RSA ₆ : -3.5*
Buchheit et al. [11]	CG	HBT	17	2	Yes	17	Velocity (km/h) at 30-15IFT Best sprint time (s) at 6 reps of 2x15m all-out shuttle sprints	AP: 18.4 $\pm$ 1.5 RSA ₆ : 6.19 $\pm$ 0.41	AP: 19.6 $\pm$ 1.4 RSA ₆ : 5.96 $\pm$ 0.31	AP: 6.52* RSA ₆ : -3.7*
Buchheit et al. [12]	HIIT	SIT	8	2	No	7	Velocity (km/h) at 30-15IFT Best sprint time (s) at 6 reps of 2x15m all-out shuttle sprints	AP: 18.8 $\pm$ 1.2 RSA ₆ : 5.79 $\pm$ 0.16	AP: 19.5 $\pm$ 1.1 RSA ₆ : 5.83 $\pm$ 0.18	AP: 3.72 RSA: 0.69
Buchheit et al. [12]	CG	S+A	8	2	No	7	Velocity (km/h) at 30-15IFT Best sprint time (s) at 6 reps of 2x15m all-out shuttle sprints	AP: 18.8 $\pm$ 1.2 RSA ₆ : 5.84 $\pm$ 0.09	AP: 18.5 $\pm$ 1.3 RSA ₆ : 5.72 $\pm$ 0.13	AP: -1.6 RSA: -2.05
Chittibabu et al. [13]	HIIT	RST	24	2	Yes	15	Estimated $\dot{V}O_{2max}$ (ml/kg/min) at 20-m shuttle run test	50.02	56.71	11.79**
Chittibabu et al. [13]	CG	CG	24	2	Yes	15	Estimated $\dot{V}O_{2max}$ (ml/kg/min) at 20-m shuttle run test	-	50.88	-
Chittibabu et al. [14]	SSGs	4x4	24	2	Yes	8	Total time (s) at 7x30m sprints Estimated $\dot{V}O_{2max}$ (ml/kg/min) at YYIRTL2	-	-	RSA: -4.19** $\dot{V}O_{2max}$: 8.83**
Chittibabu et al. [14]	CG	CG	24	2	Yes	8	Total time (s) at 7x30m sprints Estimated $\dot{V}O_{2max}$ (ml/kg/min) at YYIRTL2	-	-	No changes
Gaouri et al. [20]	HIIT	HIRT	16	2	Yes	15	Best sprint time (s) at 6 reps of 2x15m all-out shuttle sprints Velocity (km/h) 20-m shuttle run test	RSA ₆ : 6.42 $\pm$ 0.31 MAS: 14.9 $\pm$ 0.6	RSA ₆ : 6.03 $\pm$ 0.19 MAS: 15.9 $\pm$ 0.5	RSA: -6 $\pm$ 2.5** MAS: 7.2 $\pm$ 3.3**

Table 8. Cont.

Study	Intervention	Sub-group	Total sessions	Tier	Randomized	N	Outcome	Before Mean $\pm$ SD	After Mean $\pm$ SD	Before-After ($\Delta\%$)
Gaamour et al. [20]	CG	Standard in-season regimen	16	2	Yes	13	Best sprint time (s) at 6 reps of 2×15m all-out shuttle sprints Velocity (km/h) 20-m shuttle run test	RSA ₀ : 6.48 $\pm$ 0.26 MAS: 15 $\pm$ 0.7	RSA ₀ : 6.41 $\pm$ 0.25 MAS: 15.2 $\pm$ 0.6	RSA ₀ : -1.1 $\pm$ 0.4 MAS: 1.6 $\pm$ 4.4
Hammani et al. [24]	HIIT	HIRT	16	2	Yes	17	Best total time (s) at Repeated Sprint T-test Estimated VO _{2max} (ml/kg/min) and Velocity (km/h) at 20-m shuttle run test	RSA ₀ : 11.3 $\pm$ 0.7 MAS: 14.8 $\pm$ 0.6 VO _{2max} : 47.8 $\pm$ 2.5	RSA ₀ : 10.5 $\pm$ 0.6 MAS: 15.9 $\pm$ 0.5 VO _{2max} : 52.2 $\pm$ 1.9	RSA: -6.9 $\pm$ 1.3** MAS: 7.5 $\pm$ 3.3** VO _{2max} : 9.4 $\pm$ 4.1**
Hammani et al. [24]	CG	Standard handball and physical training	16	2	Yes	15	Best total time (s) at Repeated Sprint T-test Estimated VO _{2max} (ml/kg/min) and Velocity (km/h) at 20-m shuttle run test	RSA ₀ : 11.2 $\pm$ 0.4 MAS: 15.0 $\pm$ 0.7 VO _{2max} : 48.4 $\pm$ 2.9	RSA ₀ : 11.1 $\pm$ 0.4 MAS: 15.3 $\pm$ 0.6 VO _{2max} : 50.0 $\pm$ 2.6	RSA ₀ : -1.3 $\pm$ 0.6 MAS: 2.1 $\pm$ 4.3 VO _{2max} : 3.6 $\pm$ 8.2
Hermassi et al. [27]	HIIT	SI	14	2	Yes	15	Best time (s) at 6 reps of 2×15m all-out shuttle sprints Velocity (m/s) at YYIRTL1	RSA ₀ : 6.24 $\pm$ 0.09 MAS: 4.56 $\pm$ 0.27	RSA ₀ : 6.06 $\pm$ 0.10 MAS: 5.74 $\pm$ 0.30	RSA: -2.9** MAS: 25.9**
Hermassi et al. [27]	CG	Handball training	14	2	Yes	15	Best time (s) at 6 reps of 2×15m all-out shuttle sprints Velocity (m/s) at YYIRTL1	RSA ₀ : 6.19 $\pm$ 0.10 MAS: 4.47 $\pm$ 0.17	RSA ₀ : 6.15 $\pm$ 0.08 MAS: 4.34 $\pm$ 0.10	RSA ₀ : -0.6 MAS: -2.9*
Hermassi et al. [28]	HIIT	-	24	2	Yes	10	Distance (m) at YYIRTL1	1156 $\pm$ 261	1956 $\pm$ 318	69.2**
Hermassi et al. [28]	CG	Standard in-season regimen	24	2	Yes	9	Distance (m) at YYIRTL1	1333 $\pm$ 272	1129 $\pm$ 312	-15.3**
Mikalonyé et al. [37]	SSGs	Mixed	20	2	Yes	12	Distance (m) at YYIRTL1	1256 $\pm$ 401.0	1122 $\pm$ 354.0	-10.67**
Mikalonyé et al. [37]	CG	Simulated match	20	2	Yes	12	Distance (m) at YYIRTL1	1100 $\pm$ 510.0	1272 $\pm$ 532.0	15.63**

CG: control group; HIIT: high-intensity interval training; SSGs: small-sided games; SI: short intervals; HBT: handball-based training; SIT: sprint interval training; S+A: sprint-agility; RST: repeated sprint training; HIRT: high-intensity resistance training; s: seconds; m: meters; VO_{2max}: maximal oxygen uptake; YYIRT: yoyo intermittent recovery test; 30-15IT: 30-15 intermittent fitness test; RSA: repeated sprint ability; AP: aerobic performance assessed from field-based tests; MAS: maximal aerobic speed; *: significant intra-group differences; **: significant intra and inter-group differences

Table 9. Summary of main results for experimental studies with two intervention groups

Study	Intervention	Sub-group	Total sessions	Tier	Randomized	N	Outcome	Before Mean $\pm$ SD	After Mean $\pm$ SD	Before-After (Δ %)
Curțianu et al. [16]	HIIT	LI	32	3	No	9	Distance (m) at 12-min Cooper test	2385 $\pm$ 47.6	2553.1 $\pm$ 70.4	7.05*
Curțianu et al. [16]	HIIT	Tabata	24	3	No	9	Distance (m) at 12-min Cooper test	2388.5 $\pm$ 57.8	2545.1 $\pm$ 60.1	6.55*
Iacono et al. [30]	HIIT	SI	16	3	Yes	9	Distance (m) at YYIRTL1	1297.8 $\pm$ 300	1601.1 $\pm$ 192	23.3*
Iacono et al. [30]	SSGs	3 $\times$ 3	16	3	Yes	9	Distance (m) at YYIRTL1	1364.4 $\pm$ 397	1723.3 $\pm$ 327	26.3*
Jurišić [31]	HIIT	SI	16	2	No	12	Distance (m) at YYIRTL1	563.33 $\pm$ 73.28	723.33 $\pm$ 86.06	28.40*
Jurišić [31]	SSGs	3 $\times$ 3	16	2	No	12	Distance (m) at YYIRTL1	520.00 $\pm$ 61.49	611.67 $\pm$ 100.35	17.63*
Viaño-Santasmartinas et al. [52]	HIIT	SI	12	2	Yes	10	Velocity (km/h) at 30-15IFT Mean time (s) at 6 reps of 2 $\times$ 15m all-out shuttle sprints	AP: 16.77 $\pm$ 1.69 RSA _m : 6.10 $\pm$ 0.26	AP: 18.13 $\pm$ 1.74 RSA _m : 5.94 $\pm$ 0.17	AP: 8.18* RSA: -2.51*
Viaño-Santasmartinas et al. [52]	HIIT	LI	12	2	Yes	8	Velocity (km/h) at 30-15IFT Mean time (s) at 6 reps of 2 $\times$ 15m all-out shuttle sprints	AP: 16.58 $\pm$ 2.28 RSA _m : 6.18 $\pm$ 0.33	AP: 17.91 $\pm$ 2.35 RSA _m : 6.06 $\pm$ 0.29	AP: 8.19* RSA: -1.87*

HIIT: high-intensity interval training; SSGs: small-sided games; SI: short intervals; LI: long intervals; YYIRTL: yoyo intermittent recovery test; 30-15IFT: 30-15 intermittent fitness test; RSA: repeated sprint ability; AP: aerobic performance assessed from field-based tests; *: significant intra-group differences; **: significant intra and inter-group differences.

Table 10. Summary of main results for quasi-experimental studies (no control group)

Study	Intervention	Sub-group	Total sessions	Tier	Randomized	N	Outcome	Before Mean $\pm$ SD	After Mean $\pm$ SD	Before-After (Δ %)
Florin et al. [19]	HIIT	Mixed	20	3	No	18	Velocity (km/h) at 30-15IFT	17.21 $\pm$ 0.81	18.83 $\pm$ 0.38	9.5*
Bhakti [29]	HIIT	–	18	N. D.	No	18	VO _{2max} (N. D.)	1.17	2.78	137.6*

HIIT: high-intensity interval training; VO_{2max}: maximal oxygen uptake; 30-15IFT: 30-15 intermittent fitness test; *: significant intra-group differences.

Effects of high-intensity interval training on handball players' endurance performance

Except for the studies by Buchheit et al. [8, 12] and Mikalonytė et al. [37] all intervention groups have shown improvements in their field-based tests after high-intensity interval training. These improvements happened with different types of HIIT protocols, namely short intervals [1, 11, 30, 31, 52], long intervals [16, 52], SSGs [3, 14, 30, 31], and other forms of HIIT [19, 20, 24, 28]. The Yo-Yo Intermittent Recovery Test Level 1 presented results that ranged from decreases of 10.67% [37] to improvements of 69.2% [28] in the experimental groups. Regarding the improvements recorded in the study by Hermassi et al. [28] despite it being the study with the longest duration of all those presented in this systematic review (12 weeks), it is hard to justify the magnitude of the improvements, since the intervention comprised circuit training with a mix of exercises that were not very specific to the test.

However, it must be said that high-intensity circuit training has shown acute physiological responses like increased oxygen consumption, heart rate, and lactate values that might explain the results [33]. In contrast, the study by Mikalonytė et al. [37] is the only one present in this systematic review that has shown negative results from a HIIT intervention, specifically small-sided games, which is quite unexpected since team/intermittent sports players usually display superior performance in the YYIRT [5], and the players in the control group that performed match simulation recorded improvements of 15.63% in the same test. While the improvements of the subjects that participated in the match simulation are not surprising due to handball demands and their relationship with the YoYo test [5, 26], small-sided games would also be expected to cause some positive results due to their acute physiological responses needed and their appropriateness to improve handball players' physical fitness [6].

Studies that evaluated RSA by measuring time in shuttle-sprint tests have shown decreases of 7.22% [1] to increases of 0.69% [12]. Although different forms of sprint training have been shown to improve repeated sprint ability [7], this was not the case with the intervention of Buchheit et al. [12] was the only one in this systematic review with a negative effect. Curiously, this study by Buchheit et al. [12] is present in the aforementioned review as having a positive effect, but that is not the case since the best time in the shuttle sprints changed from 5.79 to 5.83 seconds. Repeated Sprint Ability has been widely considered a relevant fitness component in team sports [7, 17], and specifically in handball, it has been deemed extremely important, especially for wings [53]. RSA is a complex fitness component that depends on both metabolic and neural factors, and HIIT is considered one of the main strategies to improve this ability [7].

Concerning the physiological mechanisms underlying these results, the enhancements can be attributed to various adaptations favoring an increased dependence on aerobic metabolism for ATP resynthesis. These include heightened mitochondrial respiratory capacity, quicker oxygen uptake kinetics, an accelerated post-sprint muscle reoxygenation rate, an elevated lactate threshold, and an increased $\text{VO}_{2\text{max}}$. These factors are associated with an improved capacity to withstand fatigue during repeated sprints [7]. During repeated sprinting, the relative contribution of anaerobic glycolysis is reduced when subsequent sprints are performed, which is partially explained by an increase in aerobic metabolism [49].

Furthermore, the degradation and resynthesis rate of PCr is related to performance decrement, and a loss of muscle purine nucleotides may also occur during subsequent sprints [49]. The exercise protocol, including factors like exercise mode, sprint duration, number of repetitions, recovery duration, type of recovery, and training status, can markedly influence the relative contribution of energy systems during repeated sprint exercise. Additionally, the sprint duration plays a significant role in shaping the relative energy system contribution in the turnover of skeletal muscle ATP [49]. Normally, if athletes want to increase their RSA, they can do it by improving their muscle strength/power and, consequently, their acceleration and maximum speed, or by improving their endurance ability to improve the final sprints [7]. Finally, velocity in field-based tests has shown improvements in all the interventions present in this systematic review. Velocity at the 30-15IFT has shown improvements between 3.72% and 9.5%, and maximal aerobic speed recorded increases between 7.2% [20] and 25.9% [24].

Furthermore, the significance of rest intervals between sets should not be underestimated. The duration of rest periods plays a pivotal role in shaping motor skills and influencing ATP resynthesis during training. For instance, contrasting scenarios, such as a maximal 40-meter run with a 45-second interval emphasizing maximal power, and a similar run with a 15-second interval emphasizing anaerobic endurance, can provide valuable insights into the effects of varying rest durations. In the context of the 17 studies included in this systematic review, it became evident that demographic characteristics play a significant role in the responses to different HIIT formats. For instance, the heterogeneity in the improvements in $\text{VO}_{2\text{max}}$ and sprint performance offers valuable insights into the programming of HIIT interventions, considering biological individuality, age, and gender of handball practitioners [53]. The endurance improvements were observed across different types of HIIT protocols, including short intervals, long intervals, and small-sided games. The overall endurance improvements shown among the analyzed studies could be attributed to the increased aerobic metabolism,

mitochondrial respiratory capacity, quicker oxygen uptake kinetics, and elevated lactate threshold, which are common among HIIT protocols [2].

Despite the diversity of interval training regimens, there are benefits to all of them [53]. However, as the authors emphasize, coaches must be careful while choosing a specific form of interval training, as the manipulation of a single variable can have a direct impact on metabolic, cardiopulmonary, and neuromuscular responses to exercise [53]. It is also worth noting that physiological adaptations in response to interval training are dependent not only on the intensity of the exercise but also on the subsequent rest intervals; and excessive HIIT prescription might result in detrimental effects, which makes exercise intensity monitoring extremely important to guarantee the responsiveness of mitochondrial adaptations to changes in the duration or frequency of interval training.

Implementing these recommendations is challenging due to limited knowledge about the physiological mechanisms and adaptations induced by interval training, as well as the communication between metabolic pathways within cells [2]; and there are insufficient data to determine the responsiveness of mitochondrial adaptations to changes in the duration or frequency of interval training.

Study limitations and future research

The main limitations of this systematic review are the relatively low number of studies for each parameter, the quality of some of those studies, and the fact that most of them (13 out of 17) have been done with tier 2 athletes. The combination of these factors prevents any strong conclusions from being reached.

Given these limitations, and the lack of studies about the use of MAS in a handball context, more research on the topic should be done before reaching any conclusions. The aim of future research should also involve assessing the effects of individualizing training loads based on positional requirements. It is crucial to evaluate the disparities in internal and external load between playing positions and to characterize the training demands in the days preceding competitive events for professional handball players, aiming for better training optimization. Furthermore, an assessment of training designed to improve effectiveness during matches in the worst-case scenarios of high-performance handball players is warranted, given the significant differences between playing positions, with effect sizes ranging from moderate to very large (0.7–5.1 ES).

While most of the studies in this systematic review have presented positive effects from the HIIT interventions, there are still many uncertainties regarding the best type(s) of HIIT, the ideal volume, intensity, and frequency, and if there is any benefit in general forms of HIIT (e.g., SI, LI, SIT, RST) compared to more specific types like small-sided games since the studies in this systematic review that compared general vs specific forms of

HIIT presented mixed results. Given this, more research on these topics must be carried out before providing any specific recommendations.

Conclusion

This systematic review underscores a significant diversity in methodological approaches among the included studies, encompassing seven distinct types of High-Intensity Interval Training (HIIT) conducted over periods ranging from 4 to 12 weeks. While these varied formats consistently demonstrate positive impacts on assessed endurance performance parameters, the current body of evidence falls short of providing specific recommendations regarding the optimal selection of a particular HIIT format, including its most advantageous volume, intensity, and frequency.

It is noteworthy that a positive trend emerges, indicating that engaging in some form of HIIT twice a week holds potential benefits for enhancing endurance performance markers in handball players. However, for more definitive and tailored guidance, future studies must undertake a comparative analysis of diverse HIIT formats, exploring variations in volumes, intensities, and frequencies. This imperative research will contribute to a more nuanced understanding, enabling precise recommendations to optimize HIIT for endurance gains in the context of handball training.

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CHAPTER 5 - GENERAL DISCUSSION AND CONCLUSIONS

5.1. DISCUSSION OF THE MAIN FINDINGS

This thesis pretended to cover different topics regarding physical preparation of handball players and, as stated in the first chapter, its major goal was to summarize the main evidences regarding the impact of different strength and conditioning methods, especially plyometrics and high-intensity interval training, in the physical performance of handball athletes.

As reported in chapter 2, handball is characterized by periods of relatively stable pace interspersed with frequent bursts of intensive physical activity associated with changes in the speed and direction of movement, and includes physical collisions (as tackles), breakthroughs, clasping, fast breaks, jumping and actions like passing and throwing. Characteristics of successful athletes include endurance capacity, sprint performance, jumping ability, and a high throwing velocity, and these physical fitness attributes may help differentiate handball players' level. Given this, the two studies from this dissertation, presented in chapter 3 and 4, aimed to analyze the adaptations promoted by plyometric and high-intensity interval training in the physical attributes of handball players; the first study, a systematic scoping review, was made to describe the methods and effects of plyometric training in various physical performance variables, and in the second study a systematic review was made to evaluate the methods and effects of high intensity interval training on cardiorespiratory endurance performance.

The first study, regarding plyometric training programs in handball, has generally shown positive effects from this type of training on many different parameters, mainly jumping ability, sprinting speed, change of direction, strength, and balance. These improvements should be attributed to changes in neural and mechanical properties commonly reported with plyometric training, such as the musculotendinous stiffness and architecture, enhanced neural drive to agonist muscles, improved intermuscular coordination, greater excitability of the stretch reflex, strengthening of the elastic properties of connective tissue, or the optimization of the cross-bridge mechanics and motor unit activation. The second study, which focuses in high-intensity interval training programs and their impact on endurance performance in handball players, has shown a considerable variation in outcomes across programs, but generally demonstrated a significant positive impact of HIIT on improving endurance performance. This positive impact can be attributed to physiological mechanisms like increased mitochondrial respiratory capacity, quicker oxygen uptake kinetics, an accelerated post-sprint muscle reoxygenation rate, an elevated lactate

threshold, and an increased VO₂max, which favor an increased dependence on aerobic metabolism for ATP resynthesis and are associated with an improved capacity to resist fatigue during repeated sprints. As for the methodology, the majority of the plyometric training programs were implemented with a frequency of two times per week, using mainly cyclic exercises without any external load, in different planes, both bilaterally and unilaterally, and implementing some form of progressive overload. The HIIT programs were also conducted mostly two times per week, using different formats, but predominantly short intervals and small-sided games.

In summary, both plyometrics and high-intensity interval training are effective methods to increase physical fitness in handball players, due to different mechanisms that have been shown to be beneficial for these athletes.

5.2. CONTRIBUTION OF THIS DISSERTATION TO THE STATE OF THE ART

This dissertation has contributed to the state of the art by systematizing different aspects of the physical preparation of handball players, addressing in one document the different methods that can be utilized to improve a player's physical fitness.

When searching for systematized literature about the training of physical attributes in handball athletes, there is still not much information that can be found. The two systematic reviews (Bragazzi et al., 2020; Hadjisavvas et al., 2024) about the effects of resistance training on different manifestations of strength were referred on sub-chapter 2.3 (Strength Training in Handball), and they provide good information about the effects of resistance training on different types of strength and on-court actions like throwing, pushing or jumping.

When this dissertation was started, there was only one systematic review (Jakšić et al., 2023) regarding plyometric training in handball, and it was specifically to address the effects of additional plyometric training in the players' vertical jump ability. Meanwhile, one more study (Wang et al., 2024) was published covering the effects of plyometric training on handball players physical attributes that, in some ways, is very similar to the study that can be found in Chapter 3. However, that study only included 20 articles, while the study found in Chapter 3 included 35 articles. It must also be said that the study by Wang et al. (2024) included 6 articles (E. S. de Villarreal et al., 2022; E. S. S. de Villarreal et al., 2010; Ethiraj & Kamatchi, 2020; Gaamouri, Hammami, Cherni, Oranchuk, et al., 2023; Gaamouri, Hammami, Cherni, Rosemann, et al., 2023; Gaamouri, Hammami, Shephard, et al., 2023) that are not present in our systematic review because they didn't fit our inclusion criteria for different reasons.

Finally, the article on chapter 4 is the only systematic review to date that focuses on the endurance performance of handball players, specifically in the effects caused by different types of high intensity interval training in that performance marker, which filled a gap in the literature regarding the impact of any form of training on the energy systems of handball players.

With this, this dissertation pretends to provide a comprehensive source for many topics related to the physical preparation of handball players, providing the most updated literature regarding the state of the art.

5.3. LIMITATIONS AND FUTURE RESEARCH

The major limitation of this dissertation is directly related with the lack of specific information regarding some of the topics approached in chapter 2, as some of those don't have many quality studies that are specific to handball, and there are also the limitations of the original studies presented in chapter 3 and 4. The first review, regarding plyometric training, has provided some useful practical applications that can be drawn from a higher number of studies, which allow to extract more useful information, although there is room for more and better studies. On the contrary, the second review, about high-intensity interval training, has a lower number of studies and less useful information to allow practical recommendations to be made concerning an optimal volume, intensity and exercise selection, which limits its practical usefulness.

Given these limitations, and since there is no optimal recommended methodology in the literature regarding the application of the aforementioned methods of training, more studies should be done about the different methods of improving the physical fitness of handball players, especially PT and HIIT, in athletes of different levels, with some differences between them, namely:

- Regarding PT, future studies should address questions like better ways to evaluate plyometric intensity in contexts with limited means; comparing different types of exercises; and define optimal volumes and rest times.
- Regarding HIIT, future studies should assess the effects of individualizing training loads based on positional requirements; determine the ideal volume, intensity and frequency; and compare the different types of HIIT between each other to establish which ones are more effective and if they have any benefit compared to specific formats like small-sided games.

Once these gaps are filled, coaches will have better resources to plan their training cycles, and will be more able to prescribe better training programs to make their athletes reach the desired goals and adaptations.

5.4. PRACTICAL IMPLICATIONS AND TRANSLATION TO PRACTITIONERS

Given the results and conclusions presented by the studies that are part of this dissertation, some practical recommendations can be made regarding the implementation of these methods of training in the players' schedule.

A frequency of 2 to 3 times per week of both plyometrics and/or HIIT has shown to be effective to improve performance markers such as jumping or sprinting ability, COD or endurance performance and, if coaches want to focus on the improvement of any of these parameters, they should include it in their training cycles, taking into account the players' fitness levels and their competitive schedule. If the time available for training is limited, coaches can opt to combine plyometric and HIIT in the same workout, as there are some studies (Cherif et al., 2012; Gaamouri, Hammami, Shephard, et al., 2023; Hammami et al., 2021; Hermassi et al., 2020) that have combined both forms of training which showed positive results. If coaches have an ample time window available for training, it is suggested that both types of training should be implemented in different days, to diminish fatigue and the possibility of any interference effect. If that is the case, HIIT should be implemented further from game day, and plyometrics can be implemented closer to game day, as the former has more chance to cause fatigue than the latter.

Other forms of training, such as strength and speed training, must also be considered when planning a training cycle, and they should be taken into account when pondering the combination of different types of training, as there is literature (Cormier et al., 2020; W. P. Ebben, 2002; Freitas et al., 2017; Hammami et al., 2018, 2019; Pagaduan & Pojskic, 2020; Wang et al., 2023) that supports the combination of some of these forms of training as being beneficial and time-efficient (e.g. combining strength and plyometrics - contrast/complex training). One aspect that should not be neglected is the monitorization of the adaptations, since the response to training is highly individual and no two athletes respond to a similar stimulus in the same way (Freitas et al., 2017).

5.5. MAIN CONCLUSIONS AND TAKE-HOME MESSAGES

- Handball players are characterized by considerable physical strength, which is very important when it comes to performance, and its development is influenced by both neural and morphological factors. Strength training plays an important role among handball players, as it not only increases their fitness, but also reduces the risk of injury. Adherence to strength training might increase the levels of muscular strength and, whenever possible, the SAID principle (specific adaptations to imposed demands) must be respected, considering factors like training volume and intensity, training frequency, rest times, proximity to muscular failure, exercise selection and the speed of the repetitions. When the goal is to increase strength, these variables must be manipulated to ensure the best possible adaptation, and different forms of resistance training have shown benefits to handball players, which translates positively into actions like throwing, jumping, sprinting, change of direction and others.
- Plyometric exercises, which involve rapid stretching of a muscle before a rapid transition to a concentric contraction (stretch-shortening cycle), have been shown to be beneficial for handball players, by improving actions like accelerations, sprinting, jumping or throwing. These improvements might be explained by the changes in neural and mechanical properties reported with plyometric training, such as the musculotendinous stiffness and architecture, the strengthening of the elastic properties of connective tissue, or the optimization of the cross-bridge mechanics and motor unit activation.
- A benefit of plyometric training is that it can be done without any additional external equipment and causes while causing very little fatigue. Some important aspects to consider when programming and implementing plyometric exercises are the surface where they are done, ground contact times, the implemented regimen (intensity, volume and density) and the direction, regularity and laterality of the exercises.
- High-intensity interval training (HIIT) is a time-efficient training method for improving cardiorespiratory and metabolic function that involves repeated short (<45 s) to long (2–4 min) bouts of high-intensity exercise interspersed with recovery periods, which has been shown to be effective to improve the performance of handball players as it mimics some of the requirements that athletes encounter in game situations.

- Prescription for HIIT consists of the manipulation of up to nine variables, which include the work interval intensity and duration, relief interval intensity and duration, exercise modality, number of repetitions, number of series, as well as the between-series recovery duration and intensity. Regarding its practical application, coaches can use different methods such as short intervals, long intervals, sprint interval training (SIT) and repeated sprint training (RST) and small-sided games (SSGs).
- To improve the physical fitness of their players, coaches must evaluate what are the abilities that should be prioritized, and must carefully plan the training cycles considering the different training methods that they have at their disposal and taking into account their team's competitive schedule. While programming their training schedule, coaches should look to maximally develop the pretended abilities avoiding detrimental interferences and without excessively overloading their athletes.

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