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Applying the principles of motor learning in preventative programmes of overuse injuries in young athletes: a scoping review

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Abstract

This study aimed to review the scope of overuse injury prevention programmes in young players through the lens of application of motor learning principles. From 280 studies found in the initial search, 13 studies were selected based on a series of inclusion criteria. The selected studies were categorised based on the type of intervention resulting in multicomponent (2 studies), FIFA 11+ (5 studies), neuromuscular training (2 studies), FIFA Medical Assessment and Research Centre (F-MARC) (2 studies), educational (1 study) and stability (1 study). The studies that had an effective preventative role to reduce overuse injuries applied some principles of motor learning to their intervention, such as contextual interference, variability of practice, task constraints, the power law of practice, transfer of learning and explicit methods. There is a gap in the literature related to explicit applications of motor learning principles in the design of preventative interventions for overuse injury.

Keywords: youth sport, preventive intervention, practice design, constraints, review study.

Introduction

Current youth development systems increasingly encourage the early specialisation in sports to take advantage of training quality and quantity for winning and reaching the elite level as early as possible (Jayanthi, Pinkham, Dugas, Patrick, & LaBella, 2013). The early specialisation pathway in sports requires the selection of a single sport and a greater amount of time dedicated solely to practice from childhood (Côté, Baker, & Abernethy, 2007).

Overstressing early specialisation might have adverse effects on physical growth and development and increase the likelihood of physiological and mental diseases, as well as burnout and dropout (Bean, Fortier, Post, & Chima, 2014). Traumatic and overuse injuries are other adverse physical effects of early specialisation in children and adolescents (Hoang & Mortazavi, 2012). One of the main causes of the overuse injury following early specialisation is excessive training volume that refers to a mismatch between the physical readiness of the young athlete (maturity) and the training loads (stress) they are exposed to (Jayanthi, LaBella, Fischer, Pasulka, & Dugas, 2015). For example, one study in high school athletes showed that the risk of injury was higher when the training volume exceeded 16h per week (Rose, Emery, & Meeuwisse, 2008). In another study, it was shown that when the ratio of organised training time to free play time was greater than 2:1, the odds of overuse injury was 1.8 (Jayanthi et al., 2015). This could be explained through the lens of matching between task and organismic constraints and finding a balanced method in practice designing.

Overuse injuries occur through the repetitive loading of tissues such as bones, muscles or tendons, without sufficient time for remodelling in between bouts, this causes microtrauma in these structures leading to overuse injury (Hoang & Mortazavi, 2012). In an adolescent musculoskeletal system, cartilages and growth plates are vulnerable to stress and loading by the external forces caused during sport practice and can lead to chronic irritations, inflammations and pains at the bone-cartilage junction (Micheli, Purcell L). Repetitive microtrauma can also lead to overuse tendon injuries in the knee, shoulder, ankle and foot (Chang, Mandelbaum, & Weiss, 2007). Furthermore, repetitive compressive or tensile forces could weaken the bone (stress reaction) and can lead to a complete bone fracture (stress fracture) in young athletes (Hoang & Mortazavi, 2012).

The provision of effective prevention strategies is key for sports medicine specialists, schools/ colleges, national and international policymakers who work in youth sport. Several previous systematic reviews have examined the effectiveness of preventive interventions on youth overuse injuries, focusing on interventions such as preseason conditioning (Abernethy

& Bleakley, 2007; Herman, Barton, Malliaras, & Morrissey, 2012; Rössler et al., 2014), balance training (C. A. Emery, Cassidy, Klassen, Rosychuk, & Rowe, 2005) and sport-specific warm-up interventions (Barengo et al., 2014; Mayo, Seijas, & Alvarez, 2014). The findings demonstrated that the interventions that included plyometric and jumping exercises relative to usual training regime were significantly more effective to prevent the risks of overuse injuries (Rössler et al., 2014). In addition, a warm-up strategy that includes stretching, strengthening, balance exercises, sports-specific agility drills and landing techniques was effective to reduce the risk ratio of overuse injuries in lower limbs by 0.45 (Herman et al., 2012).

The abovementioned studies have predominantly focused on physical conditioning principles (fitness components, intensity and frequency) and there is no evidence to demonstrate how much these types of interventions applied the principles of motor learning in the design of their practice model. Motor learning is an internal process that leads to permanent changes in the motor behaviours through practice and experience (Schmidt & Wrisberg, 2008). To acquire the motor skills by permanent changes and adaptations, the practice should be designed appropriately so that the benefits of preventive programmes are maintained longer. Some of the common principles in the acquisition of motor skills that have been used in the motor learning textbooks (Schmidt & Wrisberg, 2008; Magill & Anderson, 2014) are the power law of practice (quantity of practice), the transfer of learning/ practice representativeness (similarity on skills and contexts), implicit and explicit methods (overt and covert attention), the practice organisation in terms of activity/rest ratio (mass and distributed), contextual interference (blocked and random), practice variability (constant and variable, task constraints), the feedback provision (augmented and intrinsic, delayed and immediate, frequent, less frequent, summary and bandwidth) and understanding the performer's needs.

The applications of motor learning principles in sport performance have been studied. For example, one principle of practice design that is practice representativeness (transfer of learning), the nature and types of practice tasks and environments should be similar to real contexts, has been applied extensively in tactical and technical improvement as forms of conditioned games (Pinder, Davids, Renshaw, & Araújo, 2011; Clemente, et al., 2021). For example, using different types of task constraints such as manipulating field dimensions and the number of players in small-sided games were some applications of motor learning in sport performance. The motor learning principles have also been used in the design of programmes to prevent musculoskeletal injuries in work environments (Jarus & Ratzon, 2005). In sport

injury, the main motor learning principle in prevention of overuse injuries was degrees of freedom in single joint or multi-joint coordination as a form of inter-trial variability that indicates the motor system adaptability through interactions between the system's components (Hamill, Palmer, & Van Emmerik, 2012). For example, in senior athletes a reduction in the variability was a significant factor that distinguishes injured and non-injured athletes. Adult runners with lower back pain had significantly less variability between trunk and pelvis than non-injured runners (Heiderscheit, Hamill, & van Emmerik, 2002). The plausible reason to explain the reduced variability-overuse injury relationship is that low variability causes repetitive compressive and/or tensile forces to be distributed across smaller surface areas, possibly resulting in overuse injuries, whereas optimal movement variability allows the forces to be more widely distributed, which may reduce the risk of overuse injuries (Hamill et al., 2012).

Unfortunately, applications of motor learning concepts in sport injuries are limited to the kinematic variability and there are no studies to explain the application of other motor learning principles in practice design for prevention of overuse injuries in youth athletes. Understanding the principles of motor learning can help practitioners to extend the training effectiveness beyond the season period and outside of training fields through permanent changes in motor behaviours and personal habits. Thus, the aim of this study was to review overuse injuries prevention programmes in young athletes through the lens of the motor learning principles.

Method

The design of this study was to undertake a scoping review to enable the mapping of the current literature and to identify the size of the body of literature (Arksey & O'Malley, 2005) and inform more specific future reviews and/or primary research studies.

The review followed the methodological frameworks of previous scoping reviews (Arksey & O'Malley, 2005). The framework involved five steps: 1) defining a research question, 2) comprehensive and systematic identification of relevant studies, 3) independent and objective screening and selection of studies, 4) extraction and charting of the data, and 5), summary of the findings for recommendations for future research.

Scope of review/research question

The scope of the review and the research question was defined using the population, intervention, comparison and outcome (PICO) format. The operational definitions, outcomes

of interest and the key terms search strategy were decided and finalised through a consensus in the panel that was formed from experts in both sports medicine and sports science. The research questions were: Are motor learning principles used in the design of interventions to prevent overuse injuries in young athletes? An overuse injury was defined as a repetitive, submaximal stress and loading of the musculoskeletal system without giving the body sufficient time to recover (Hoang & Mortazavi, 2012). Another common definition is an injury occurring in the absence of a single, identifiable traumatic cause. We defined motor learning concepts as principles of practice for skill acquisition, performance enhancement or permanent changes in motor behaviours (Schmidt & Wrisberg, 2008). The examples of principles were contextual interference (CI), variability of practice, explicit learning methods, transfer of learning and representativeness, task variations, massed/distributed practice, the power law of practice, adaptation and task constraints (Schmidt & Wrisberg, 2008; Magill & Anderson, 2014). The definitions of concepts are presented in the Table 1.

Literature search strategy

The following electronic databases were systematically searched between 1990 and March 2020: MEDLINE, EMBASE, PsycINFO, CINAHL, Scopus, ERIC, SportDiscus, Cochran Library, PUBMED and AMED. The key terms that were used in combination with “children/youth/adolescents” were “overuse injury”; “prevention”; “intervention”; “training”; “sport practice” and “task constraints”. Furthermore, reference lists were checked from all relevant reviews that were found in addition to articles were identified. Key terms were adapted from studies that aimed to examine an intervention to prevent overuse injuries in young athletes (Rössler et al., 2014).

Study selection

Studies were included if they met the following criteria: 1) included overuse injuries, 2) included children and adolescent athletes between ages 5 and 19 years, 3) were interventional, prospective or randomised controlled trials, 4) the article was published in a peer-reviewed journal, 5) published in English. The studies were excluded if: 1) the type of study was descriptive, epidemiological, cross-sectional or correlational 2) it was a literature review study, 3) other types of injury (traumatic/acute) were considered and 4), it was documented in conference proceedings or a dissertation/thesis. Two reviewers (M.S. & S.P.) independently applied the inclusion criteria to select the relevant articles and resolved all disagreements by consensus. The selection process was carried out at title, abstract and full-text levels. First, the reviewers read the selected titles and identified relevant studies,

excluding the irrelevant titles. The abstract and full text of selected studies was then reviewed to finalise the list.

Data extraction and charting of data

Two independent reviewers participated in the charting of the data that were extracted from the full-text of selected studies. The information extracted by the first reviewer (M.S.) was verified by the second reviewer (S.P.). All discrepancies were discussed between reviewers until a consensus was reached. Unlike most systematic reviews, scoping reviews do not reject studies based on a risk of bias assessment (Arksey & O'Malley, 2005); therefore, we did not carry out any quality assessment of the selected studies. The important information extracted was organised by study domain, the participants' demographic measures, the type of study, and the nature of the intervention as presented in Table 2. The classification of studies into different practice designs was carried out based on the principles of motor learning (Schmidt & Wrisberg, 2008).

Results

Of the 280 articles initially identified, 13 studies met the inclusion criteria. The flowchart detailing the selection process is presented in Figure 1. The majority of studies were published between 2011 and 2019 (6 studies). Some of them were published between 2006 and 2010 (4 studies) and 3 studies were published between 1990 and 2005 indicating that the topic is still in its infancy and a contemporary issue in the field of injury prevention.

-----Insert Figure 1 here-----

Types of study

The majority of studies were cluster randomised controlled trials (11 studies) that investigated the effect of a specific intervention on the prevention of overuse injuries. The quasi-experimental study (1 study) and prospective control intervention (1 study) were other types of study in this area.

Types of sport

The types of sport in the selected studies were soccer (9 studies), basketball (1 study), handball (2 studies) and field hockey (1 study).

Concepts of practice designing

The natures of interventions in the selected studies were multicomponent (Barboza et al 2019; Olsen et al 2005), FIFA 11+ (Soligard et al 2008; Rossler et al 2018; Owoeye et al 2014; Beaudouin et al 2019, Longo et al 2012), neuromuscular training (LaBella et al 2011; Emery & Meeuwisse 2010), F-MARC (Stefen et al 2008; Junge et al 2002), educational (Scase et al 2006) and stability (Wedderkopp et al 1999). These interventions have used different principles of motor learning in practice design that are summarised below (see Table 2 for more information about the applications of concepts in different studies).

1.Contextual interference

Only one study used random practice method (Barboza et al 2019) and the other studies used blocked practice method.

2.Variability of practice

Only one study used the variable practice method (Barboza et al 2019) and the other studies used the constant practice method. For example, in variable practice the movement parameters were changed in each trial, whereas in constant practice the same parameters (balance time, maximum exertion) were maintained. The lowest task variation was in the stability intervention with 3 different exercises (Wedderkopp et al 1999) and the highest task variation was using a multicomponent warm up with 19-20 different exercises (Olsen et al 2005; Barboza et al 2019). The other studies used between 6-14 different exercises.

3.Transfer of learning

All types of intervention had some elements of learning transfer and representativeness through similarity to target sport skills and target contexts. The multicomponent warm up (Barboza et al 2019; Olsen et al 2005) integrated sport-specific skills such as foot works, fundamental movement skills and technical skills to their warmup routine. The FIFA 11+ (Soligard et al 2008; Rossler et al 2018; Owoeye et al 2014; Beaudouin et al 2019, Longo et al 2012), the neuromuscular training (LaBella et al 2011; Emery & Meeuwisse 2010) and F-MARC (Stefen et al 2008; Junge et al 2002) used sport-related skills such as foot works, jump/land techniques and manoeuvring but had less technical sport-specific skills. The stability (Wedderkopp et al 1999) and educational interventions (Scase et al 2006) mainly focused on postural balance and had some elements of jump and throw as sport-specific drills. The majority of interventions spent less time in sport-specific situations, had individual or pair challenges rather than team activity and with less emphasis on the integration to real

game situations. In the stability intervention, all activities were designed to be natural part of the playing movement to facilitate transfer to real fields (Wedderkopp et al 1999).

4.The power law of practice

The interventions in all studies were delivered in the whole season between 8-12 months and only one study (Scase et al 2006) had a short duration (4.5 months). The multicomponent interventions had 12-15min duration and was practised 1-2 times per week. The FIFA 11+ programmes had 20min duration and were practised at least 2 times per week. The neuromuscular training interventions were practised on a daily basis for 15minutes. The F-MARC intervention was practised in 15 consecutive sessions initially and then once per week thereafter. It had 10 sets. The educational intervention and stability intervention had 30min and 10-15min duration, respectively.

5.Explicit learning

The warmup interventions in all studies were embedded to the usual training sessions and had an explicit structure such as instructions and demonstrations. There is not any information on how the participants received individual feedback.

6.Progression/adaptation

The multicomponent intervention had weekly progression in terms of intensity, difficulty and frequency (Barboza et al 2019; Olsen et al 2005). The FIFA 11+ defined the progression through three levels of task difficulty (Soligard et al 2008; Rossler et al 2018; Owøye et al 2014; Beaudouin et al 2019; Longo et al 2012). The other interventions did not report any principle of progression.

7.Matching to personal constraints

The design of one study was matched with sex and age groups (Barboza et al 2019). The F-MARC was tailored to performance level and the amount of team training (Junge et al 2002; Steffen et al 2008). The other studies did not mention any practice considerations to match with personal characteristics.

Overuse injury rate

Overall, the findings showed that any structured warm up intervention that added to the current training programme was effective in reducing the risk of overuse injury in young athletes. The majority of studies (10 studies) reported a significant reduction in the rate of

injury (Beaudouin et al 2019; Emery & Meeuwisse 2010; Junge et al 2002; LaBella et al 2011; Rossler et al 2018; Soligard et al 2008; Wedderkopp et al 1999; Olsen et al 2005; Owoeye et al 2014; Scase et al 2006) and only 3 studies did not report any change (Steffen et al 2008; Barboza et al 2019; Longo et al 2012).

-----Insert Table 1 here-----

Discussion

The aim of this study was to review the scope of overuse injuries prevention programmes in young players through the lens of application of the motor learning principles. The findings showed that structured warm up routines were effective in reducing the rate of overuse injuries in young players. It seems that the current preventive interventions that mainly focused on physical conditioning principles also implicitly followed the principles of motor learning to enhance physical adaptations. Although some studies did not report any significant reduction in the rate of injuries (Steffen et al 2008; Barboza et al 2019; Longo et al 2012), but the lack of effectiveness cannot be associated with the motor learning principles because they applied a range of motor learning concepts same as other studies. The common principles that have been used in their practice design were contextual interference (mainly blocked practice), variability (mainly constant practice), task constraints (low to high task variations), the power law of practice (short duration warm up, but in a whole season), transfer of learning and representativeness (more similarity with target skills) and explicit methods (providing instructions and demonstrations). The other principles that have not been used extensively in many studies were augmented feedback provision to individualise the training needs and adaptations, the similarity between practice contexts and target contexts to simulate game situations, the methods of progression and matching the task difficulty to the personal constraints. The following sections will discuss the applications of motor learning principles in overuse injuries prevention programmes.

Task constraints and variability of practice

Although the selected studies were interested in motor fitness components such as strength, power, balance and flexibility as main factors in intervention designing, they also applied some levels of task constraints such as low contextual interference and practice variability (blocked and constant practice schedule) in their warmup interventions. Only one included study (Barboza et al 2019) used a multicomponent warm up intervention with variation in the type of task along with parameter change through random and variable practice schedule. The

effects of low contextual interference and constant practice in performance enhancement in different motor skills have been shown in previous studies, but learning and higher adaptations were demonstrated in random and variable practice methods that require continuous changes in the movement patterns and parameters (Schmidt & Lee 2019). Movement variability plays an important role in the overuse injuries (Hamill et al., 2012), however, no evidence of variability as an intervention design principle was found in any of the included studies. Overuse injuries usually occur through the repetitive stress that leads to microtrauma in bones, muscles or tendons (Hoang & Mortazavi, 2012); hence, amending the type and frequency of exposure to the repetitive actions through variations might be beneficial for injury prevention (Hamill et al., 2012). Increasing variations in the practice routine for the prevention of overuse injuries requires special modifications in the practice per se. The increased variability through changes in the coordination pattern in blocked practice may be beneficial for the prevention of injuries when the same movement pattern is repeated frequently, for example in throwing, jumping or running (Hamill et al., 2012). Some examples of embedding tasks variability in the selected studies were changing the running directions (left/right/forward/backward), pace (slow/medium/high) and movement patterns (jog/spring/hop/skip). Through task variations, young athletes can build boundary conditions and play with the possible fluctuations (task variations) not only to individualise the task based on organismic constraints such as strength, speed, body size and other physical and motor fitness components, but also to cope with the situatedness of the individual that is changing their emotional and fatigue boundary conditions constantly (Corso, 2018; Kelso, 1995). It has been hypothesised that performing repetitive muscular activities through a variable coordination pattern could be an effective practice strategy to prevent the risk of overuse injuries (Moraiti, Stergiou, Ristanis, & Georgoulis, 2007).

Transfer of learning and practice representativeness

In this review, the majority of interventions were effective in the prevention of overuse injuries because they used some forms of transfer of learning to target movement patterns or target contexts (e.g. game situations). For example, using the same movement patterns that were used in the game situations or changing the practice contexts were examples of practice representativeness in these studies (see Table 2). Plummer et al (Plummer et al., 2019) showed that sport-specific injury prevention programmes were more effective (67-85%) than the general prevention programmes (29-57%) in increasing motor performance measures that are related to overuse injuries, such as strength, power, balance and speed/agility. The main

characteristic that defines a preventive intervention more specific to the sport was the type of tasks (Plummer et al., 2019). For example, if the programme includes many activities that are used in the sport itself (e.g. starting, stopping, twisting, turning, running, jumping, landing, shuffling, pushing, pulling, hitting, throwing, catching, hopping, accelerating, decelerating, sliding, blocking), it would better represent the sport instead of compound exercises such as plank, squat and bench press. The success of other preventive interventions such as balance training and plyometric exercises may be explained in terms of matching the exercises (e.g. landing and jumping) to the situations with a high risk of injuries (e.g. landing, changing the direction and contact) (Rössler et al., 2014). The success of the FIFA 11+ warm-up programme also is referred to the specificity of practice principle (Steffen et al., 2013). Only a few studies in this review had such level of representativeness (Wedderkopp et al 1999; Barboza et al 2019; Olsen et al. 2005; Scase et al., 2006). One key principle of sports practice is representative learning design that implies that when designing practice, tasks must take place in situations that simulate key aspects of a performance environment which athletes can use as information to regulate their future actions (Brunswik, 1956). The exercises for the prevention of overuse injuries are the same as those for acquisition of the skill and should consider the similarity between the performance context (e.g. competitions) and practice context in terms of perception and decision-making and the similarity between the types of activity and motor skills (Pinder, et al., 2011). This might suggest that the activities and conditions that simulate the real-game situations with the same intensity, frequency and types are equally effective for the acquisition of sports skills and improving physical conditioning for injury prevention because of body adaptations in game-like practice conditions (Hill-Haas, et al., 2011).

Progression and individualised practice designing

The progression and matching the task difficulty to the personal constraints were applied in some included studies such as the multicomponent intervention (Barboza et al 2019) and the FIFA 11+ (Soligard et al 2008; Rossler et al 2018; Owøye et al 2014; Beaudouin et al 2019; Longo et al 2012). The progression and individualisation in practice designing can be explained theoretically. According to dynamical systems theory (Kelso, 1995), the emergence of a movement pattern is constrained by individual characteristics and the environment, and the role of a coach and practitioner is to manipulate the tasks to enable the performers to explore the possible movement solutions for better outcomes and with minimum risks. If the

repetitive muscular actions during sports are not scaled individually, they increase the risk of chronic injuries (DiFiori, 2002). For example, the inter-individual variability during growth (body dimensions) and maturation (body functions) in bones, muscles and soft tissues, make the young athletes more vulnerable to tolerate the external loads during physical activity (Corso, 2018). In addition, there are individual differences between children and adolescents in their rate of maturation (early-mature/ late-mature) that significantly affect their body's response to the external loads and risk of injuries (Le Gall, Carling, & Reilly, 2007). For example, the risk of injury was increased 6 months after peak height velocity (PHV) in young footballers (Bult, Barendrecht, & Tak, 2018) that shows the vulnerability of the body to external loads in some critical periods of growth and development. Because the age of PHV is not the same in members of a sport team, the practice organisation and design should be individually appropriate to prevent the risk of overuse injury. Constraining the tasks, sports equipment and environments to promote movement variability could be effective strategies to reduce the risk of injury in young athletes who are at the early development stage of specialisation

The power law of practice

The quantity of practice is one of the important elements of skill acquisition and performance enhancement (Schmidt & Wrisberg, 2008). There is no doubt that one of the reasons for effectiveness of the selected studies in reducing the rate of overuse injuries was the amount of practice because they delivered the intervention in a whole season and were embedded as part of the training routine. The interventions such as FIFA 11+ and multicomponent had a structured routine and were performed at least twice per week to maintain the adaptation at optimal level. The neuromuscular training performed in daily basis and had structured routine same as other warmup interventions. The warmup interventions in the selected studies had 12-20min duration that could be enough to rehearse the selected exercises.

However, the training volume should be determined carefully to avoid oversteering and overuse injuries especially following early specialisation. The reason is that excessive training and stress is usually mismatched with physical and physiological readiness (maturity) in young athletes (Jayanthi, LaBella, Fischer, Pasulka, & Dugas, 2015). For example, when the training volume exceeded 16h per week (Rose, Emery, & Meeuwisse, 2008) or the ratio of organised training time to free play time was greater than 2:1 (Jayanthi et al., 2015) the risk of injury in young athletes was higher.

Limitations

We acknowledge some limitations to this study. Firstly, despite the selection of young athletes in this study, inclusion covered a broad range of ages from 5-19 years. Understanding the effectiveness of preventive interventions based on age differences and levels of maturation requires further study. Second, the quantification of overuse injuries was based on clinical inputs or self-report. It seems that other objective methods such as using player loads and other related training parameters could be added and used in future studies as predictors of overuse injuries. Lastly, as this was a scoping review, the quality of studies was not evaluated, and the reported effectiveness might be affected by the methodological issues in sampling and measurement.

Conclusion

This is the first study that reviewed the applications of motor learning principles in the design of preventive overuse programmes. The findings of this scoping review showed that structured warmup routines that were effective in reducing the risk of overuse injuries in young athletes implicitly have used some principles of motor learning in practice designing. However, there is a major gap in the literature related to applications of motor learning principles in designing the overuse preventive programmes by using other principles such as feedback provision and transfer of learning to real situations to extend the effectiveness of such interventions in a longer period of time and beyond the training sessions.

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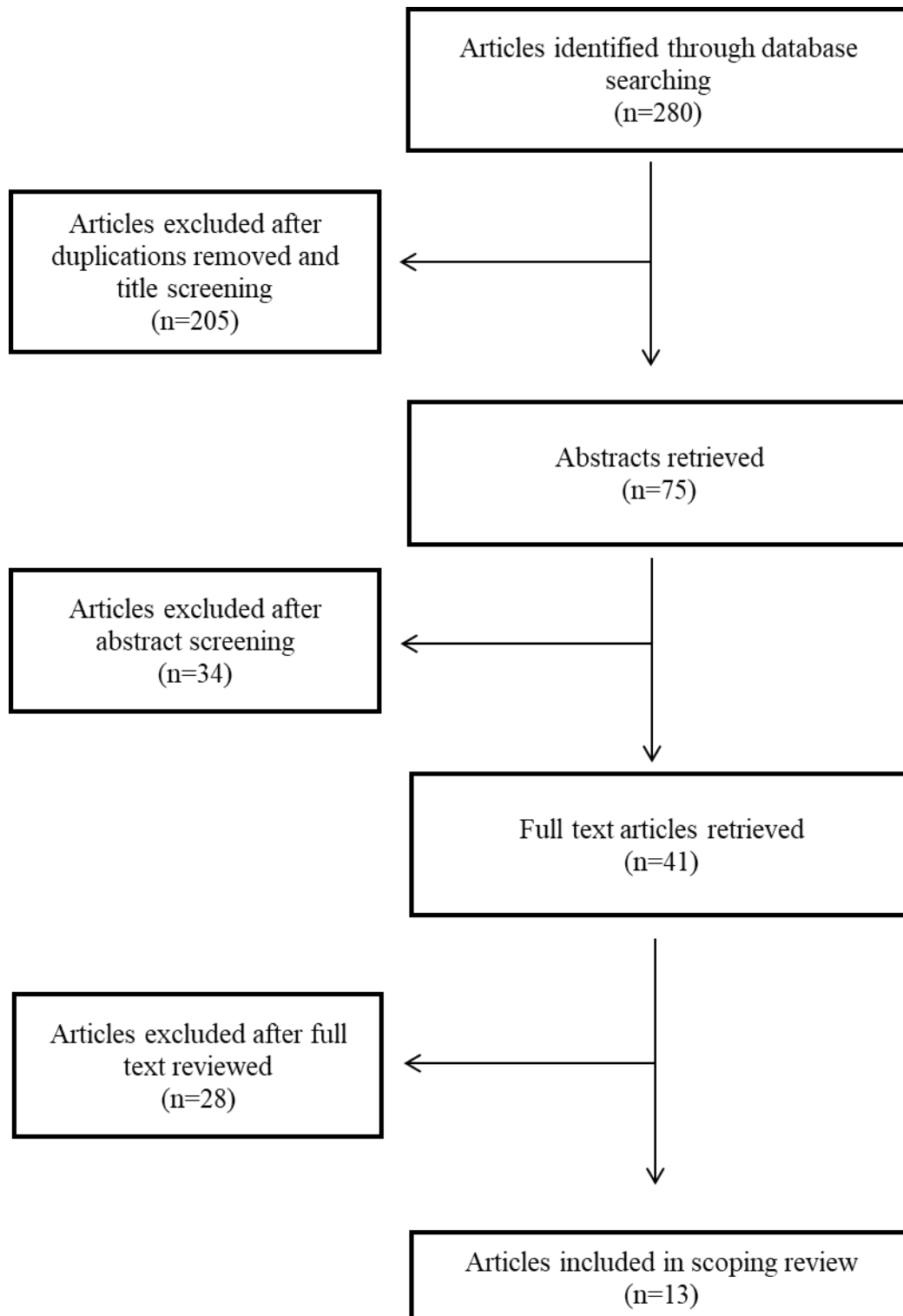


Figure 1. Flow diagram of selection of studies focusing on motor learning principles in young athletes.

Table 1: The definition of key motor learning principles (Schmidt & Wrisberg, 2008; Magill & Anderson, 2014).

Concept	Definition
1. Adaptations	It refers to generalisability or how generalisable the performance of a skill is.
2. Contextual interference	Interference (memory disruption) results from performing various tasks or skills within the context of practice. The practice is blocked (changing the task between successive sets) or random (changing the task between trials).
3. Constraints	The certain features (person, environment, and task) serve to contain or act as boundaries on performance.
4. Explicit learning	Conscious and intentional acquisition of motor skills through verbal instructions and demonstrations.
5. Feedback	Information about the performance that is received by sensory modalities or external sources.
6. Practice distributions	A practice schedule in which the amount of rest between practice sessions is short (massed) or long (distributed).
7. Practice representativeness	The amount of similarity between the practice task/context and target task/context.
8. The power law of practice	The improvements in performance due to the amount of practice follow a specific pattern.
9. Transfer of learning	The influence of previous experiences on performing a skill in a new context or on learning a new skill.
10. Variability of practice	The variety of movement and context characteristics a person experiences while practicing a skill.

Table 2: The main characteristics of participants, practice organisation, quality and quantity.

Study	Participants	Type of study	Intervention dose and contents	Type of warm up	Practice design	Representativeness
Barboza et al (2019)	135 field hockey players (between the ages of 11 and 12 years; boys and girls) in the intervention group and 156 players (between the ages of 12 and 14 years) in the control group	Quasi-experimental	9 months intervention; three-phase warm up (12min): Preparation phase (2 reps; 4min) had a mix of locomotor skills along with changing parameters such as pace, laterality and range of motion; in sport-specific phase (4min) they ran between cones and changed the directions and speed by dribbling; in movement skills phase (12 reps; 4min) they maintained posture stability in different forms in constant mode and jump/land by changing the leg	Multicomponent structured weekly warm up	-Random practice through changing the movement patterns within each rep -Variable practice through changing the movement parameters in each trial Task variation: 19 different exercises -Sex and age matched -Weekly progression in intensity, frequency and difficulty	-Similarity to target sport skills: foot works, fundamental skills, dribbling, ball manipulation -Similarity to target context: 33% of time allocated to sport-specific practice and 64% spent on general fitness
Beaudouin et al (2019)	Children's soccer clubs divided into an intervention (2066 children; girls and boys; between the ages of 10 and 13 years) and a control group (1829 children; girls and boys; between the ages of 10 and 13 years)	Cluster-randomised controlled trial	9 months (2 times/week) intervention; three-phase warm up (20min): running phase (12 reps; 8min) had a mix of 6 different running modes along with changing parameters such as pace and laterality; in plyometric and balance phase (10 reps; 10min) they practised 6 functional core stability, balance and jump in static and dynamic fashions; in complex running phase (4 reps; 2min) they ran across the pitch at 75-80% max pace and combined exaggerated arm and hip swings during running.	FIFA 11+ structured weekly warm up	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters (balance time, maximum exertion) Task variation: 14 different exercises -Progression through different levels of difficulty	-Similarity to target sport skills: same foot works, jump/land, manoeuvring, but lacks sport-specific skills drills -Similarity to target context: individual or pair challenges, lack of football manipulation skills, low level of tactical and decision-making through team activity

Emery & Meeuwisse (2010)	Adolescent between the ages of 13 and 18 years (girls and boys) from 60 soccer teams; 32 training (n=380), 28 control (n=364) groups	Cluster-randomised controlled trial	12 months (daily) intervention. Two-phase structured warm up (15min): general phase (5min) including aerobic, statics and dynamic stretching; the neuromuscular training (10min) including sets of eccentric hamstring (Nordic stretch), lunges, leg raise, single-leg jump and wobble stance throwing. All exercise were performed with maximum exertion.	Neuromuscular training structured weekly warm up	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters such as balance time, maximum exertion Task variation: 8 different exercises	-Similarity to target sport skills: same foot works, jump/land, but lacks sport-specific skills drills -Similarity to target context: individual or pair challenges, lack of football manipulation skills, low level of tactical and decision-making through team activity
Junge et al (2002)	194 youth soccer players from 7 teams (male amateur players aged between 14 and 19 years) which were took part in a prevention program and 7 teams which were instructed to train as usual in the control group	Prospective controlled intervention	12 months (daily) intervention. Improvement of warm-up, regular cool-down, taping of unstable ankles, adequate rehabilitation, and promotion of the spirit of fair play as well as specially designed warm up routines that included 10 sets of core stability (15s, 6 reps), balance (15s, 11 reps), plyometric (10-15 reps), Nordic hamstring (5 reps).	F-MARC structured weekly warm up and education	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters (balance time, maximum exertion) Task variation: 11 different exercises -It was tailored to performance level and the amount of team training	-Similarity to target sport skills: same foot works, jump/land, but lacks sport-specific skills drills -Similarity to target context: individual or pair challenges, lack of football manipulation skills, low level of tactical and decision-making through team activity
LaBella et al (2011)	1492 female soccer and basketball athletes in urban public high schools which their schools were randomized to intervention (between the ages 15 and 18 years) and control (between the ages 15 and 19 years) groups	Cluster-randomised controlled trial	12 months (daily) intervention. Two-phase structured warm up (15min): general phase (5min) including aerobic, statics and dynamic stretching; the neuromuscular training (10min) including sets of eccentric hamstring (Nordic stretch), lunges, leg raise, single-leg jump and wobble stance throwing. All exercise were performed with maximum exertion.	Neuromuscular training structured weekly warm up	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters such as balance time, maximum exertion Task variation: 8 different exercises	-Similarity to target sport skills: same foot works, jump/land, but lacks sport-specific skills drills -Similarity to target context: individual or pair challenges, lack of football manipulation skills, low level of tactical and decision-making through team activity

Longo et al (2012)	Seven basketball teams in intervention group (80 male players; between ages 11 and 16 years), and 4 teams in control group (41 male players; between ages 11 and 18 years)	Cluster-randomised controlled trial	9 months (at least 2 times/week) intervention. Three-phase structured warm up (20min): running phase (12 reps; 8min) had a mix of 6 different running modes along with changing parameters such as pace and laterality; in plyometric and balance phase (10 reps;10min) they practised 6 functional core stability, balance and jump in static and dynamic fashions; in complex running phase (4 reps;2min) they ran across the pitch at 75-80% max pace and combined exaggerated arm and hip swings during running.	FIFA 11+ structured weekly warm up	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters (balance time, maximum exertion) Task variation: 14 different exercises -Progression through different levels of difficulty	-Similarity to target sport skills: same foot works, jump/land, manoeuvring, but lacks sport-specific skills drills -Similarity to target context: individual or pair challenges, lack of football manipulation skills, low level of tactical and decision-making through team activity
Olsen et al (2005)	1837 players (girls and boys) from 120 team handball clubs aged 15-17 years; 958 players in the intervention group; 879 players in the control group	Cluster-randomised controlled trial	12 months intervention (15 consecutive session and then once per week). Four-phase structured warm-up programme (15min): general readiness (5min,30s, 1 rep) of different running patterns by changing directions, and pace; technical rehearsal (4min,30s, 5 reps) of cutting and jump shots; balance on wobble disk (4min,90s, 2 reps) of multipoint movements; strength and power (2min,3 sets and 10 reps) including squat, forward jumps and Nordic hamstring.	Multicomponent warm up structured weekly warm up	-Blocked practice through changing the movement patterns between sets -Constant practice through maintain the same parameters (balance time, maximum exertion) in 2nd-4 th phases and variable practice in the 1 st phase Task variation: 20 different exercises	-Similarity to target sport skills: foot works, fundamental skills, dribbling, ball manipulation Similarity to target context: 60% of time allocated to sport-specific practice and 40% spent on general fitness)

Owoeye et al (2014)	20 soccer teams (414 male players aged 14 - 19 years) were divided into two groups of intervention and control	Cluster-randomised controlled trial	9 months (at least 2 times/week) intervention. Three-phase structured warm up (20min): running phase (12 reps; 8min) had a mix of 6 different running modes along with changing parameters such as pace and laterality; in plyometric and balance phase (10 reps;10min) they practised 6 functional core stability, balance and jump in static and dynamic fashions; in complex running phase (4 reps;2min) they ran across the pitch at 75-80% max pace and combined exaggerated arm and hip swings during running.	FIFA 11+ structured weekly warm up	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters (balance time, maximum exertion) Task variation: 14 different exercises -Progression through different levels of difficulty	-Similarity to target sport skills: same foot works, jump/land, manoeuvring, but lacks sport-specific skills drills -Similarity to target context: individual or pair challenges, lack of football manipulation skills, low level of tactical and decision-making through team activity
Rossler et al (2018)	3,895 child soccer players (ages 9-13 years; girls and boys) divided into intervention (from 128 teams; 2,066 players) and control (from 115 teams; 1,829 players) groups	Cluster-randomised controlled trial	8 months (at least 2 times/week) intervention. Three-phase structured warm up (20min): running phase (12 reps; 8min) had a mix of 6 different running modes along with changing parameters such as pace and laterality; in plyometric and balance phase (10 reps;10min) they practised 6 functional core stability, balance and jump in static and dynamic fashions; in complex running phase (4 reps;2min) they ran across the pitch at 75-80% max pace and combined exaggerated arm and hip swings during running.	FIFA 11+ structured weekly warm up	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters (balance time, maximum exertion) Task variation: 14 different exercises -Progression through different levels of difficulty	-Similarity to target sport skills: same foot works, jump/land, manoeuvring, but lacks sport-specific skills drills -Similarity to target context: individual or pair challenges, lack of football manipulation skills, low level of tactical and decision-making through team activity

Scase et al (2006)	16 teams from the elite national soccer between 15 and 19 years in Australia. 114 male soccer players were in intervention group and 609 male players in the control group	Cluster-randomised controlled trial	4.5 months (daily) intervention. The 30-minute session intervention programme taught players six landing, falling, and recovery skills (prone fall, backward fall, sideways rolling, landing and back shoulder roll).	Teaching landing skills structured weekly warm up	No information on practise design in terms of order and duration per exercise is reported Task variation: 6 different exercises	-Similarity to target sport skills: postural adjustments -Similarity to target context: transfer from the mats to game situations
Soligard et al (2008)	1892 female soccer players from 125 Norway clubs aged 13-17 years (1055 players in the intervention group; 837 players in the control group)	Cluster-randomised controlled trial	8 months (every training session) intervention. Three-phase structured warm up (20min): running phase (12 reps; 8min) had a mix of 6 different running modes along with changing parameters such as pace and laterality; in plyometric and balance phase (10 reps;10min) they practised 6 functional core stability, balance and jump in static and dynamic fashions; in complex running phase (4 reps;2min) they ran across the pitch at 75-80% max pace and combined exaggerated arm and hip swings during running.	FIFA 11+ structured weekly warm up	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters (balance time, maximum exertion) Task variation: 14 different exercises -Progression through different levels of difficulty	-Similarity to target sport skills: same foot works, jump/land, manoeuvring, but lacks sport-specific skills drills -Similarity to target context: individual or pair challenges, lack of football manipulation skills, low level of tactical and decision-making through team activity

Steffen et al (2008)	1091 youth female soccer players in intervention group and 1001 players in control group (aged 13-17 years)	Cluster-randomised controlled trial	8 months intervention (15 consecutive session and then once per week). Improvement of warm-up, regular cool-down, taping of unstable ankles, adequate rehabilitation, and promotion of the spirit of fair play as well as specially designed warm up routines that included 10 sets of core stability (15s, 6 reps), balance (15s, 11 reps), plyometric (10-15 reps), Nordic hamstring (5 reps).	F-MARC structured weekly warm up and education	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters (balance time, maximum exertion) Task variation: 10 different exercises -It was tailored to performance level and the amount of team training	-Similarity to target sport skills: same foot works, jump/land, but lacks sport-specific skills drills -Similarity to target context: individual or pair challenges, lack of football manipulation skills, low level of tactical and decision-making through team activity
Wedderkopp et al (1999)	Female handball players aged 16-18 years. 111 players in intervention group and 126 players in control group	Cluster-randomised controlled trial	9 months intervention. The programme was using an ankle disk for 10-15 min at all practice sessions. It also was consisted of 2 or more functional activities (e.g. one and two-leg stairs jumping, playing with a medicine ball) for all major muscle groups.	Stability structured weekly warm up	-Blocked practice through changing the movement patterns between sets -Constant practice through maintaining the same parameters (balance time, maximum exertion) Task variation: 3 different exercises	-Similarity to target sport skills: ankle stability, jumping and throwing skills -Similarity to target context: individual or pair challenges, lack of ball manipulation skills, low level of tactical and decision-making through team activity. All activities were designed to be natural part of playing movement to facilitate transfer to real fields.
