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Application of mobility training methods in sporting populations: A systematic review of performance adaptations

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ABSTRACT
This systematic review investigates influences of mobility training in sporting populations on performance outcomes. The search strategy involved Embase, MEDLINE Complete, Sports Discus and manual search from inception to March 2022. Mobility training studies with a minimum three-week, or 10-session duration in healthy sporting populations of any age were included. Twenty-two studies comprising predominantly young adult or junior athletes were analysed from 319 retrieved articles. Performance outcomes were strength, speed, change of direction, jumping, balance, and sport-specific skills. Fifteen studies randomized participants with only four indicating systematic allocation concealment and blinding of outcomes assessors in only one study. In 20 of 22 studies mobility training was of some benefit or helped to maintain sports performance to a larger degree than control conditions. Control conditions, which were generally no activity conditions, were primarily non-significant. The majority of evidence suggests that a range of mobility training methods may improve key sports performance variables or are unlikely to impair performance over time. Therefore, coaches can consider the potential benefits of including comprehensive mobility programmes with minimal risk of impairing performance. Higher-quality studies in homogenous populations are necessary to confirm performance changes.

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KEYWORDS
Stretching; range of motion (ROM); exercise movement techniques; yoga; Pilates; athletic performance

Introduction

Contemporary exercise techniques emphasizing the development of adequate movement ability are now relatively common in most sports training programmes (Brooks & Cressey, 2013). Such techniques including dynamic stretching, yoga, Pilates, dance and gymnastics exercises can aid to help mobility, which according to a number of definitions, such as the *Oxford Dictionary*, describe "the ability to move or be moved freely and easily" (Mobility, 2023) or "the facility of movement" (Booth, 2008). In a sporting context, mobility is also described as an athlete's ability to move through range of motion (ROM) in a stable and coordinated manner (Brooks & Cressey, 2013). While mobility is considered important to develop in most athletes, demanding training schedules and the necessity to develop other athletic traits, may limit its application. Therefore, it is of interest to the practitioner to know if mobility training can benefit aspects of sports performance.

Mobility is related to but different from flexibility, which refers to the ability of a muscle and surrounding soft tissue structures to elongate. Flexibility is typically associated with stretching to improve passive ROM, whereas mobility is associated with dynamic activities to improve active ROM or active flexibility. While adequate flexibility is required for good mobility, this must also be balanced with strength and stability to efficiently utilise the available ROM in a sporting capacity.

There are a wide range of methods available to athletes to improve strength; such as bodyweight training, isolated machine-based exercises, multi-joint free weight exercises, weightlifting movements and derivatives, plyometric training, eccentric training, potentiation complexing, unilateral versus bilateral training and variable resistance training (Suchomel et al., 2018). Similarly, mobility may be achieved from a range of non-specific or sports-specific preparatory exercises from disciplines such as dynamic stretching, yoga, Pilates, dance and gymnastics. These mobility training methods are often included in the non-specific preparatory exercises of a warm-up or cool down, or as a separate cross-training session. The purpose of mobility training in athletic populations goes beyond aspects of a basic non-specific preparatory warm-up, to maintain or develop ROM and refine motor patterns (Booth, 2008; Brooks & Cressey, 2013). It has been suggested that no single method of mobility training is ideal for all athletes and that programming should be targeted to the athletes' needs (Brooks & Cressey, 2013). While there has been research investigating the acute effects of some of these modalities, the research is not well synthesized in terms of the short- to medium-term outcomes of mobility training on sports performance.

Dynamic stretching is recommended as a pre-performance routine in most sports because of the demonstrated small acute increases in power, sprint, jump and balance

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performance (Behm et al., 2016, 2021; Opplert & Babault, 2018). Dynamic stretching is defined by "controlled movement through the active ROM for each joint" (Fletcher, 2010)(p1), and differs from ballistic stretching which is typically higher-velocity and less controlled, and dynamic warm-up activities (e.g., jogging, running, skipping, hopping), which may not necessarily utilize full ROM (Behm, 2018). Dynamic stretching can also be distinguished as either active, meaning it is performed while moving, or static, being performed stationary (Turki-Belkhiria et al., 2014). The logical progression in a complete athletic warm-up is to begin with dynamic warm-up activities through a moderate ROM, progress to dynamic stretching through full ROM and finally ballistic sports-specific explosive movements. Despite its widespread use in athletic warm-ups, training studies summarising the short- to medium-term effects of dynamic stretching on performance are less expansive than those describing its acute effects (Behm, 2018).

Dance and gymnastics are two disciplines which require high levels of ROM for the performance of technical skills (Skopal et al., 2020). Therefore, exercises from these disciplines may assist to develop mobility for other sports. Structured dance interventions have been shown to be effective in improving functional movement capacity in a range of populations (Fong Yan et al., 2018), and this benefit may extend to athletes who have greater movement demands than the average population. Gymnastics is a recommended fundamental sport for all junior athletes (Balyi et al., 2016); however, its potential to enhance athletic performance in adult athletes has only been explored in dance populations (Skopal et al., 2020).

Yoga is an ancient mind body practice originating from India combining breathing techniques (pranayama), physical postures (asana), meditation practice and relaxation (LaSala et al., 2021). The physical postures may increase flexibility, coordination, and muscle strength, while breathing and meditation practices serve to calm and focus the mind (Büssing et al., 2012). A large number of yoga styles exist which vary in their emphasis on the physical component of the practice (Cramer et al., 2016). Research suggests that yoga is beneficial in reducing sport-related anxiety (Cadieux et al., 2021), but less is known about the physical benefits of yoga for athletes.

Pilates, previously known as Contrology, was developed by Joseph Pilates in World War I as a means of rehabilitating patients to restore strength and mobility (Sekendiz et al., 2007). It subsequently developed into an exercise system revolving around training the core to stabilise the torso facilitating optimal movement (Sekendiz et al., 2007). Exercises in traditional Pilates repertoire promote mobility of the spine and elongation of the muscles with simultaneous maintenance of core stability. Therefore, Pilates closely relates to the goals of a mobility training session in facilitating unrestricted yet controlled movement.

Yoga and Pilates are two movement modalities that are continually expanding and evolving from their traditional roots to become embedded in mainstream fitness. Contemporary use of yoga or Pilates typically honour the original principles of the disciplines with the flexibility to expand the repertoire to include a wide variety of movement patterns (Amin & Goodman, 2014; Sekendiz et al., 2007). This provides opportunity for sessions to be tailored to the needs of specific sports. However, reviews on these disciplines tend to focus on the exercise techniques as a therapy rather than physical fitness modality (Field, 2016; Kamioka et al., 2016).

The importance of mobility training to facilitate athletic performance remains debatable. Together or in isolation, these mobility training techniques have the potential to assist athletes to improve and/or maintain and utilise their ROM in a controlled and coordinated manner. However, the scientific understanding of if, and how such adaptations may improve athletic performance is lacking. A lack of synthesis or consensus on the short- to medium-term training adaptations in highly trained athletes has also been observed. Therefore, the aim of this systematic review is to provide an overview of the literature investigating the effects of short- to medium-term mobility training protocols on sports performance. This will serve to increase the knowledge of strength and conditioning and sports science professionals on the potential applications of mobility training in a variety of athletic populations.

Materials and methods

Experimental approach to the problem

This study did not require ethical approval, as this review collected and synthesized data from previous studies in which informed consent was already obtained by study researchers. Detailed electronic searches were performed in the following databases from inception to March 2022; Embase, MEDLINE Complete, and Sports Discus (accessed via EBSCOhost Database). Additional articles were sourced via Google Scholar and Research Gate. Articles were searched via the title, abstract and relevant subject terms using the PICO framework:

P: sport* OR athlet* OR player* OR elite
I: mobility OR "range of mo*" OR flexibility OR Stretch* OR Yoga OR Pilates OR gymnastics OR danc*
C: "routine training" OR "static stretch*" OR "sports-specific exercises"
O: performance OR FMS OR jump* OR strength OR power OR speed OR sprint* OR agility OR kick* OR throw* OR bat* OR bowl* OR serv*

Terms relating to "chronic" or "long-term" were used to filter out studies on the acute effects of stretching. The key words were combined using Boolean terms AND, or OR, or NOT to find relevant articles. Routine training refers to the training sessions included in the regular weekly training schedule. Static stretching refers to holding a muscle in a lengthened position for a prescribed period of time (Behm, 2018). Sports-specific exercises refer to a physical intervention specially designed for the requirements of a specific sport that is not focused on improving mobility. The references from relevant articles were examined to identify additional studies on the topic. The complete search strategy used for MEDLINE Complete is presented in Supplemental Digital Content 1.

Subjects

Randomized and non-randomized longitudinal intervention studies were included in this review. The following inclusion criteria were applied: (1) the participants were sporting populations of any age group; (2) the mobility protocol lasted for a minimum duration of three weeks or ten sessions; (3) the comparators were either single-group or multiple-group trials; (4) outcome measures for sports performance could be either sports specific skills or muscle performance measures; (5) publications in English. Exclusion criteria included (1) subjects with any current injury, disease or dysfunction; (2) subjects not identifying as sporting populations; (3) interventions shorter than three weeks or ten sessions; (4) mobility was not a primary component of the intervention; (5) protocols with only one stretching exercise; (6) stretching protocols which did not include dynamic stretching; (7) no assessment of sport or muscle performance; (8) non-English articles; (9) conference abstracts or books.

Procedures

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) was used as a guide for study procedures (Page et al., 2021). Screening and quality assessment was independently performed by two authors (LS, ED). Discrepancies were discussed until a consensus was reached. The study quality assessment criteria from a similar review on chronic stretching (Medeiros & Lima, 2017) was used and included presence or absence of randomization, allocation concealment, blinding of outcome assessors, description of losses and intention-to-treat analysis. Intention-to-treat analysis was confirmed when the number of participants allocated to groups were identical as the number used in analysis. Studies without a clear description of these assessment procedures were considered as unclear or not reporting. Data extracted included participants' age, sport and participation level, mobility intervention type, volume and duration, control measures, assessments, results, and study limitations. Authors were contacted by email when necessary to clarify any protocol related queries. Studies were grouped according to the mobility modalities used and common performance outcomes were categorised into strength, jumping, speed, change of direction (COD), balance, and sport-specific skills.

Statistical analysis

The level of significance interpreted for each study was $p \leq 0.05$. Effect sizes were interpreted for Cohen's d as trivial < 0.2, small 0.2-<0.5, moderate 0.5-<0.80, large ≥ 0.80 or partial eta square (η^2) interpreted as small (0.01), moderate (0.06) or large (0.14) (Cohen, 1977). When not reported, effect sizes were calculated as the mean change in performance of the experimental group divided by the initial standard deviation. A meta-analysis was not conducted due to the high study heterogeneity.

Results

Literature selection

The literature search presented 319 articles, of which 66 were identified as duplicates and 11 articles added from additional sources (Figure 1). Screening of titles and abstracts excluded 204 articles that were irrelevant or did not satisfy the eligibility criteria. Thirty-eight articles were further excluded after detailed analysis or when the full text could not be retrieved. The final number of studies included in this review was 22. The key study characteristics and findings are presented in Table 1.

Research quality

The quality assessment scores for each paper are presented in Table 2. Fifteen studies randomized participants (Alipasali et al., 2019; Arihiro et al., 2018; Biswas et al., 2021; Da Cruz et al., 2014; Fathi et al., 2019; Ferri-Caruana et al., 2020; Greco et al., 2019; Herman & Smith, 2008; Raj et al., 2021; Rao et al., 2021; Solomons et al., 2021; Sudhakar & Padmasheela, 2012; Taleb-Beydokhti, 2015; Turki-Belkhiria et al., 2014; Wilson et al., 1992) with only four of those indicating systematic allocation concealment (Herman & Smith, 2008; Raj et al., 2021; Solomons et al., 2021; Vaidya et al., 2021). Blinding of outcomes assessors was only confirmed in one study (Alricsson et al., 2003). Ten studies included a description of losses (Alipasali et al., 2019; Alricsson et al., 2003; Arihiro et al., 2018; Ferri-Caruana et al., 2020; Greco et al., 2019; Herman & Smith, 2008; Holt, 2016; Raj et al., 2021; Rao et al., 2021; Wilson et al., 1992) and only one included dropouts in the analysis (Greco et al., 2019).

Sporting populations

The sporting populations included in the studies are presented in Table 1. The majority included a single sporting discipline, one study used a different sport as the control (Polsgrove et al., 2016). Sporting disciplines included softball (Holt, 2016), rugby union (Arihiro et al., 2018; Raj et al., 2021; Solomons et al., 2021), cricket (Biswas et al., 2021; Rao et al., 2021; Vaidya et al., 2021), wrestling (Herman & Smith, 2008), soccer (Polsgrove et al., 2016; Turki-Belkhiria et al., 2014), artistic (Ahmadabadi et al., 2015) or rhythmic gymnastics (Ferri-Caruana et al., 2020), canoeing (Álvarez-Yates & Garcia-Garcia, 2020), cross-country skiing (Alricsson et al., 2003), volleyball (Alipasali et al., 2019; El-Sayed et al., 2010; Greco et al., 2019; Sudhakar & Padmasheela, 2012), basketball (Da Cruz et al., 2014), handball (Taleb-Beydokhti, 2015), Australian rules football (Donaldson, 2010), and powerlifting (Wilson et al., 1992). Junior athletes (mean age ≤18 years) with two to nine years sports experience were included in eight articles (Ahmadabadi et al., 2015; Alricsson et al., 2003; Álvarez-Yates & Garcia-Garcia, 2020; Biswas et al., 2021; Da Cruz et al., 2014; Ferri-Caruana et al., 2020; Greco et al., 2019; Solomons et al., 2021). The remaining involved young adult athletes of training experience between four and 12 years (Alipasali et al., 2019; Arihiro et al., 2018; Donaldson, 2010; El-Sayed et al., 2010; Herman & Smith, 2008; Holt, 2016; Polsgrove et al., 2016; Raj et al., 2021; Rao et al., 2021; Sudhakar &

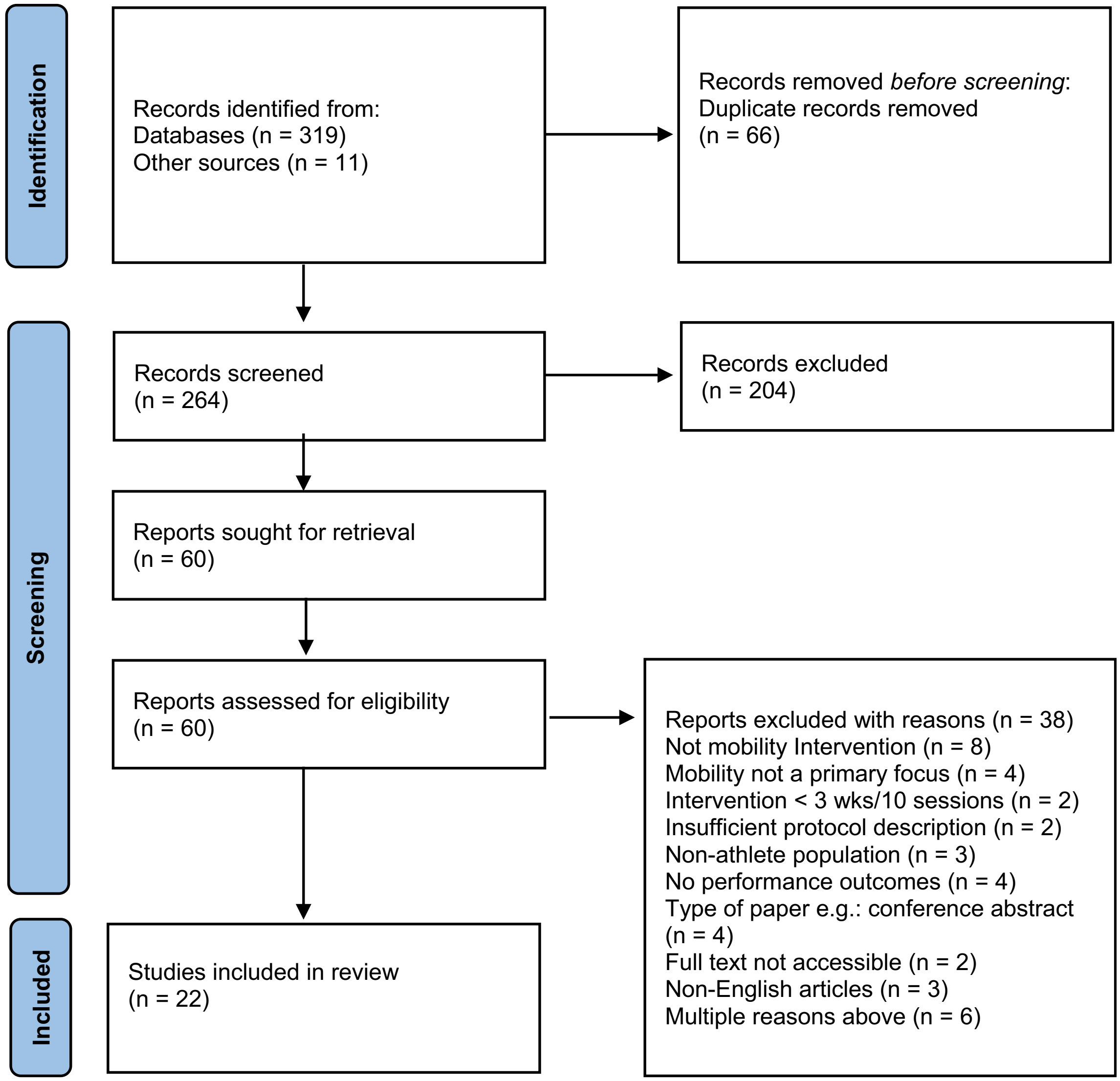

Figure 1. PRISMA (preferred reporting items for systematic reviews) flowchart illustrating the inclusion and exclusion criteria used in the systematic review.

Padmasheela, 2012; Taleb-Beydokhti, 2015; Turki-Belkhiria et al., 2014; Vaidya et al., 2021; Wilson et al., 1992). Masters' athletes were not involved in any of the studies. Athletes ranged from amateur or club level (Ahmadabadi et al., 2015; El-Sayed et al., 2010; Taleb-Beydokhti, 2015; Vaidya et al., 2021), state, regional or provincial level (Alipasali et al., 2019; Biswas et al., 2021; Da Cruz et al., 2014; Donaldson, 2010; Ferri-Caruana et al., 2020; Greco et al., 2019; Rao et al., 2021; Solomons et al., 2021), college or university athletes (Arihiro et al., 2018; Herman & Smith, 2008; Holt, 2016; Polsgrove et al., 2016; Sudhakar & Padmasheela, 2012; Turki-Belkhiria et al., 2014), national or elite level (Alricsson et al., 2003) or combined levels (Álvarez-Yates & Garcia-Garcia, 2020; Wilson et al., 1992). Two to three sports sessions per week was the minimum training frequency reported versus daily training in higher-level athletes.

Overall effect of mobility training on performance

To assess the effect of mobility training on sports performance, studies were classified and examined according to the mobility training modalities; dynamic stretching and/or dynamic warm-up, combination stretching, yoga, Pilates or dance. No articles using gymnastics training met the inclusion criteria. Overall, 20 of 22 studies provided evidence that mobility may help to improve or maintain performance according to the following criteria; mobility training improved one or more performance outcomes significantly more or with a larger effect size than routine training (Ahmadabadi et al., 2015; Alipasali et al., 2019; Alricsson et al., 2003; Arihiro et al., 2018; Biswas et al., 2021; Da Cruz et al., 2014; Donaldson, 2010; Ferri-Caruana et al., 2020; Greco et al., 2019; Herman & Smith, 2008; Rao et al., 2021; Solomons et al., 2021; Sudhakar & Padmasheela, 2012; Turki-Belkhiria et al., 2014; Wilson et al., 1992), and/or static stretching (Ferri-Caruana et al., 2020; Herman & Smith, 2008; Sudhakar & Padmasheela, 2012), mobility training maintained performance and avoided either a significant or large effect size decline compared with routine training (Holt, 2016; Raj et al., 2021), mobility training improved one or more performance outcomes with a large effect

Table 1. Study characteristics.

Author (year)	Study Design	Sample (n)Mean age ± SD (years)	Mobility Protocol	Measures	Key Findings
Taleb-Beydokhti & Haghshenas (2015)	Experimental longitudinal repeated measures	12 amateur handball players 1966 ± 4.02 DS vs SS	2 x wk/6wks in WUPLB 10 mins, 15s e/s SS Int: point of tension/mild discomfort	Illinois Agility	DS: NS d=0.17+ SS: ↓ d=0.69+
Sudhakar & Padmasheela (2012)	Experimental longitudinal pre- and post-measures	30 collegiate male volleyball players18-25 DS vs SS vs CG	4 x wk/4 wks in WUPFB 30s, 15 reps, rest 10s CG: no stretching	VJ	EG 1: ↑ * d=1.17+ EG 2: ↓ * d=0.71+ CG: ↑ * d=0.58+
Alipasali et al. (2022)	Experimental longitudinal pre- and post-measures	27 regional male volleyball players 21.6 ± 2.1 SS: (n = 11) vs DS: (n = 7) vs CG: (n = 9)	3 x wk/6wks LB 4 min 10s x 2 sets, rest 10s Int: Max ROM – no pain CG: no stretching	4.5 & 9m Sprint	SS & DS: ↑ * CG: NS* n^2=0.341 & 0.363
Herman & Smith (Holt, 2016)	Experimental longitudinal repeated measures	24 male national collegiate division I wrestlers DWU: (n = 10) 20.3 ± 0.3, vs SS: (n = 10) 19.5 ± 0.3	5 x wk/4 wks 15 mins in WUP Supervised DWU: FB calisthenics: x 10 reps/ex moderate pace & movement drills x 5 ex SS: 30s x 1 set. 8 ex	Peak Torque: Quadriceps/ Hamstrings Medicine Ball ThrowPush Ups Pull Ups Sit Ups Broad Jump 600m Run 300-yard Shuttle	DWU: ↑ 11% DWU / SS: NS DWU: ↑ 4% DWU: ↑ * 3% / SS: ↓ *3.7% DWU / SS: NS DWU: ↑ 11% DWU: ↑ 4% DWU: ↑ * 2.4% SS: ↓ * 2.5% DWU: ↑ 2%
Turki-Belkhiria et al. (2014)	Randomized experimental trial with repeated measures.	37 uni experienced male soccer players Active DS (ADS) (n=11) 20.6 ± 1.0, vs Static DS (SDS) (n=11) 20.99 ±1.0, vs GC: (n=15) 20.8±1.8	3 x wk/8 wks in WUP ADS: moving SDS: stationary CG: no stretching 5 LB ex 14 reps x 2 sets Rest: 10s b/w sets Speed: slow & continuous	SJ Height SJ Force SJ Power CMJ Height CMJ Force CMJ Power 10/20m Sprint RSA	SDS ↑ * 4.6% d=1.0 ADS ↑ 5.3% d= 0.83 CG: NS* ADS ↑ d=0.30+ ↑ SDS d=0.92+ / ↑ ADS d=0.68+ ↑ CG d=0.23 SDS ↑ * 5.3% d=1.41 ADS ↑ 3.4% d=0.37 SDS ↑ * 7.2% d=2.62 ADS ↑ # 12.7% d= 3.6 SDS: ↑ * 3.9% d=1.1 ADS: ↑ 3.3% d=0.85 CG: NS*# (all) CG: ↓ * 5.4/2.5% d=0.11/0.66ADS: NS* / SDS: NS d=0.55+ NS ↓ all groups ADS/SDS d=0.38+/ 0.75+
Ahmadabadi et al. (2023)	Experimental study repeated measures.	16 female artistic gymnasts 9.62 ±1.45 DWU: (n=8) CG: (n=8)	3 x wk/4 wks in WUP 30 mins DWU: jogging & FB mobilization + periodized DWU 12 FB ex (5 general, 7 vault specific) CG: jogging & FB mobilization only	Hard floor: DL/SL Balance Soft Floor: DL/SL Balance Vault Performance	↑ d=0.46+/ NS d=0.35+ ↑ d= 1.34+/ NS d=0.28+ DWU: ↑ * d=2.01+ CG: NS*
Ferri-Caruana et al (Field, 2016).	Longitudinal experimental study	18 female regional/ national level rhythmic gymnasts 13 ± 2 Dynamic ROM (DROM) (n= 9) CG: (n= 9)	4 x wk/7 wks 20-21 mins DROM: hip exs,15s x 5 reps/ ex (5 s concentric lift, 5 s isometric hold, 5 s eccentric lower), Int: 9/10 CG: routine hip SS: 90s/ex	R & L 1RM Isometric HF Strength SJ Height Split leap FT	DROM R: ↑ * d=2.45+ SS R: NS* d= 3.0+ DROM L: ↑ *: d=3.43+ SS L: NS* d= 2.25+ DROM & SS: ↑ d=<0.2+ NS: DROM ↑ d=0.86+ SS ↓ d=0.5+

(*Continued*)

Table 1. (Continued).

Author (year)	Study Design	Sample (n)Mean age ± SD (years)	Mobility Protocol	Measures	Key Findings
Álvarez-Yates & Garcia-Garcia (Alricsson et al., 2003)	Longitudinal quasi-experimental design with known assignment groups	16 male canoeists 17.75 ± 1.73 CS 1: (n=5) SS + DS + PNF national team CS 2: (n=5) SS & DS: regional level CG: (n=6) recreational level	EG1: 20 sessions, 2 -3 x wk/8 wks LB & Trunk ~138 mins/wk Supervised EG 2: 21 sessions 3 x wk/7 wks LB & Trunk ~79 mins/wk No supervision CG: no stretching	Horizontal Leg Press Power Average Speed	NS EG 1 & 2 CS 1: R ↑ d=0.30$^+$/ L ↑ d=0.05$^+$ CS 2: R ↑ d=0.09$^+$/ L ↑ d=0.48$^+$ NS EG 1 & 2 CS 1: R ↑ d=0.15$^+$/ L ↑ d=0.16$^+$ CS 2: R ↓ d=0.70/ L ↓ d=0.09$^+$
Wilson et al. (1992)	Experimental longitudinal pre- and post-measures design	18 male powerlifters mixed levels CS: (n=9) 24.2 ± 2.8 CG: (n=7) 28.5 ± 5.0	EG: 2 x wk/8 wks 10-15 mins supervised 4 UB ex's post-training, periodized: 2 loaded static, 8-20 s, 6-9 reps x 2 sets 1 static against wall: 30s e/s x 3 sets 1 dynamic with pole: 6-9 reps x 2 sets CG: routine training	Max Bench Press Load: Rebound Concentric	CS: ↑ 5.4 % d=0.29$^+$ CG: NS CS: NS ↑ 4.5% d=0.22$^+$ CG: NS
Donaldson (El-Sayed et al., 2010)	Quasi-experimental longitudinal repeated measures design	11 male Aussie Rules players 19-28 CS: (n=6) CG: (n=5)	EG: 7 x wk/6 wks 2 mins LB DS: Leg swings x 20 reps + SS: 2 x 15s CG: no stretching	Kicking Distance	CS: ↑ 4.1m CG: NS
Holt (Kamioka et al., 2016)	Quasi-experimental longitudinal repeated measures	26 division I college softball athletes YG: (n=13) 20.01 ± 1.12 CG (n=13) 19.64 ± 1.57	EG: 3 x wk/6 wks Supervised FB Yoga 20 mins CG: routine training	H:Q Strength Throwing Kinematics: Stride LengthOther Variables	NS YG: NS/CG: SL ↓ * η_p^2= 0.310NS
Polsgrove et al (Suchomel et al., 2018).	Quasi-experimental longitudinal repeated measures	26 division II male Uni athletes. YG: soccer team (n=14) 19.8 ± 1.05 CG: baseball team (n=12) 20.3 ± 1.06	EG: 2 x wk/10 wks Supervised Yoga 60 mins in morning CG: routine training	Stork stand	YG: ↑ * d=0.62$^+$ CG: NS* ↓ d=0.47$^+$
Vaidya et al. (2021)	Experimental longitudinal repeated measures	60 recreational club level cricketers YG: 18.3 ± (0.9) CG: 18.4 ± (1.0)	EG: 3 x wk/12 wk 45 min FB cross training EG: supervised Yoga CG: Bowling/power exs	LB/Trunk Isometric Strength Medicine Ball Throw VJ Height Bowling Performance	All performance attributes: YG & CG: ↑ d=>0.9 d: YG > CG
Raj et al (Sudhakar & Padmasheela, 2012).	Experimental longitudinal repeated measures	31 male rugby players local club YG: 19.1 ± 0.9 CG: 19.6 ± 0.9	EG: 2 x/wk, 8 wks Supervised FB Yoga 60 mins CG: routine training	Sprint 5m 10m 30m	All NS YG: ↑ 3.2% d=0.60$^+$ CG: ↑ 0.4% d=0.00$^+$ YG: ↑ 0.7% d=0.07$^+$ CG: ↓ 0.4% d=0.18$^+$ YG: ↓ 0.2% d=0.06$^+$ CG: ↓ 4.4% d=0.81$^+$
Biswas et al (Behm et al., 2021).	Experimental longitudinal repeated measures	30 male district cricket players YG: (n=15) 17.6 ± 1.5 CG: (n=15) 18.0 ± (1.5)	EG: 5 x wk/ 4 wks Supervised Yoga FB 30 mins pre-training CG: routine training	Sit Ups Endurance 50m Sprint 4*10m Shuttle Stork Stand	YG: ↑ * / CG: NS* YG: & CG: NS YG: ↑ * d=0.2$^+$/ CG: NS* YG: ↑ * / CG: NS*

(*Continued*)

Table 1. (Continued).

Author (year)	Study Design	Sample (n)Mean age ± SD (years)	Mobility Protocol	Measures	Key Findings
Rao et al (Taleb-Beydokhti, 2015).	Experimental longitudinal repeated measures	82 domestic male cricket players YG: 42 21.1 ± 4.2 CG: 40 21.7 ± 3.3	EG: 5 x wk/6 wks Supervised Yoga 80 mins, pre-fitness training CG: routine training	Core Strength Tests Stork Stand YBT	YG: ↑ * d=1.02-1.31+ YG: ↑ * d=0.92-2.11+ YG: ↑ * d=1.28-1.66+ (except YBT Delta)
Arihiro et al (Amin & Goodman, 2014).	Experimental longitudinal repeated measures	23 elite collegiate rugby union players PG: (n=9) 19.5±1.5 SS: (n=8) 19.3 ± 1.7 CG: (n=6) 20.7 ± 1.3	20 mins x 10 sessions ~ 3 wks, pre-weight training PG: 6 Pilates hip joint flexion exs, supervised SS: self-guided, LB hip exs CG: routine training	Overhead Squat Depth	PG ↑ *# η_p^2=0.867 SS ↑ * η_p^2=0.254 CG: NS# η_p^2=0.053
Greco et al (Heneghan et al., 2020).	Randomized controlled study	20 female provincial level volleyballers 15.1 ± 0.7 PG: (n=10) CG= (n=10)	2 x wk/8 wks PG: ~30 min periodized FB mat Pilates supervised CG: routine training	SJ Height Power CMJ Height power	PG & CG: ↑ d=0.23+/ 0.11+ η_p^2=0.54 (main effect time) PG: ↑ d=0.38+/ CG: NS PG: ↑ d=1.0+/CG: NS η_p^2=0.54 (time effect) PG: ↑ d=1.02+/ CG: NS η_p^2=0.29 (time effect)
Da Cruz et al (Cramer et al., 2016).	Experimental repeated measures	15 male state basketball athletes 15.7 ± 0.8 PG: (n=8) CG: (n=7)	2 x wk/6 wks PG: ~1hr periodized studio equipment LB/trunk Pilates supervised 7 ex, 15-20 reps, 2-3 sets, 45s rest CG: routine training	VJ Tests SJ Variables Height/Force Power/ VelocityCMJ Variables 9.14m Shuttle	All NS: PG & CG PG ↑ d=0.12/d=0.28 ↓ d=0.05/d=0.67 PG ↑ d=0.3-1.56 NS d=0.00
El-Sayed et al (Fathi et al., 2019).	Longitudinal repeated measures	20 club volleyball players PG: 19.4 ± 0.68 No CG	4 x wk/6 wks Cross training: WUP running & jumping, SS & periodized Pilates, relaxation	Jump Height/ Distance/FT Power/ Contact Time Block Performance Attack Performance	PG: ↑ 7.86% -12.60% d=2.94-22.68+ PG: ↓ 11.71/5.50% d=2.11+/ 6.18+ PG: ↑ 24.94% d=4.76+ PG: ↑ 10.06 % d=3.37+
Alipasali et al. (2019).	Prospective controlled intervention study	20 elite cross-country skiers 5 male & 5 female 13.6 ± 1.0	DG: 180 mins, 2 x/wk, 8 months Supervised Dance training CG: routine training	Slalom Test (speed) Hurdle Test (speed/agility)	DG: I: ↑ (3 & 8 months) d=0.36+ 8 months/CG: NS DG: I: ↑ * (3 & 8 months) d=0.71+ 8 months CG: ↓ * (8 months) d=0.44+
Solomons et al. (2021)	Crossover experimental design	54 academy rugby players 18 ± 0.81 TC: (n=28) CT: (n=26)	8 wk intervention/4 wk washout Treatment: 16 x 60 mins supervised dance program (warm-up, rhythmic movement to music, stretching cool down) Control: routine training TC: treatment first CT: control first	Medicine ball throw Push Up Test 2 mins Crunches Pull Up Test SL Squat VJ Height	CT: ↑ treatment phase d=0.75+ TC: ↑ treatment phase d=0.44+ NS either group/phase TC: ↑ treatment phase d=0.79+ CT: ↑ control phase d=0.49+ TC: ↓ control phase d=0.60+
				Illinois Agility (without ball) SEBT	CT & TC: ↑ control phase d=0.35-38+ CT & TC: ↑ 2nd block (selected directions) d=0.22-0.94+

EG: experimental group, CG: control group, wk(s): week(s), mins: minutes, s: seconds, reps: repetitions, ex(s): exercise(s), Int: intensity, e/s: each side, R: right, L: left, WUP: warm-up, ROM: range of motion, SS: static stretching, DS: dynamic stretching, CS: combination stretching, DWU: dynamic warm-up, PNF: proprioceptive neuromuscular facilitation, CR: contract-relax, LB: lower body, FB: full body, UB: upper body, DL: double leg, SL: single leg, HF: hip flexor, VJ: vertical jump CMJ: countermovement jump, SJ: squat jump, RSA: repeated sprint ability, SEBT: star excursion balance test, YBT: Y balance test, H:Q: hamstring to quadriceps ratio Uni: university, Max: maximum, d/ηp2: effect sizes, NS: non-significant, */#: Significant change between groups , ↑: performance increase, ↓: performance decrease, +:effect size calculated (not reported).

Table 2. Risk of bias of the included studies.

Study	Randomization	Allocation concealment	Blinding (outcome assessors)	Description of losses	Intention-to-treat analysis
Taleb-Beydokhti (2015)	Yes	NI	NI	No	NI
Sudhakar & Padmasheela (2012)	Yes	NI	NI	No	NI
Alipasali et al. (2019).	Yes	NI	NI	Yes	No
Herman & Smith (2008)	Yes	Yes	No	Yes	No
Turki-Belkhiria et al. (2014).	Yes	NI	NI	NI	NI
Ahmadabadi et al. (2015).	NI	NI	NI	No	NI
Ferri-Caruana et al. (2020).	Yes	NI	NI	Yes	No
Álvarez-Yates & Garcia-Garcia (2020)	No	No	NI	No	NI
Wilson et al. (1992).	Yes	NI	NI	Yes	No
Donaldson (2010)	NI	NI	NI	No	NI
Holt (2016)	No	No	NI	Yes	No
Polsgrove et al. (2016).	No	No	NI	No	NI
Vaidya et al. (2021).	Yes	Yes	No	No	NI
Raj et al. (2021).	Yes	Yes	NI	Yes	No
Biswas et al. (2021).	Yes	NI	NI	NI	NI
Rao et al. (2021).	Yes	NI	No	Yes	No
Arihiro et al. 2018).	Yes	NI	NI	Yes	No
Greco et al. (2019).	Yes	NI	NI	Yes	Yes
Da Cruz et al. (2014).	Yes	NI	NI	No	NI
El-Sayed et al. (2010).	No	No	NI	No	NI
Alricsson et al. (2003).	No	No	Yes	Yes	No
Solomons et al. (2021).	Yes	Yes	NI	No	NI

size comparable to another sports-specific training intervention (Vaidya et al., 2021), or when no control or equivalent comparison condition was used but mobility training significantly improved performance with a medium to large effect size (El-Sayed et al., 2010; Polsgrove et al., 2016). Two studies were deemed to have no impact on performance based on non-significant performance changes which were primarily trivial in effect size (Álvarez-Yates & Garcia-Garcia, 2020; Taleb-Beydokhti, 2015). No studies reported significant performance declines in any performance variable following mobility training.

Mobility protocols

Dynamic stretching or dynamic warm-up

Six of seven studies found some beneficial effects to muscle or sports performance following either lower body (Alipasali et al., 2019; Ferri-Caruana et al., 2020; Turki-Belkhiria et al., 2014), or full body (Ahmadabadi et al., 2015; Herman & Smith, 2008; Sudhakar & Padmasheela, 2012), dynamic stretching or dynamic warm-up training programmes. The training interventions were typically a warm-up for a routine training session. Four studies found dynamic stretching to be preferable to an active control of static stretching (Ferri-Caruana et al., 2020; Herman & Smith, 2008; Sudhakar & Padmasheela, 2012; Taleb-Beydokhti, 2015), and one study found the two methods equally effective (Alipasali et al., 2019). Three studies found a dynamic stretching intervention to be preferable to either no stretching (Sudhakar & Padmasheela, 2012; Turki-Belkhiria et al., 2014), or as an addition to the existing mobility routine (Ahmadabadi et al., 2015). Four studies were distinguished as using dynamic stretching (Alipasali et al., 2019; Sudhakar & Padmasheela, 2012; Taleb-Beydokhti, 2015; Turki-Belkhiria et al., 2014), versus three studies utilising a range of dynamic warm-up activities (Ahmadabadi et al., 2015; Ferri-Caruana et al., 2020; Herman & Smith, 2008). Reported benefits following dynamic stretching in adult athletes included large effect size improvements in jumping ability in soccer and volleyball (Sudhakar & Padmasheela, 2012; Turki-Belkhiria et al., 2014), improvement in short-distance sprint performance in volleyball players (Alipasali et al., 2019), and maintenance of speed in soccer (Turki-Belkhiria et al., 2014). Agility remained unchanged in handball players following 12 sessions of dynamic stretching in contrast to a significant decline in the static stretching control group (Taleb-Beydokhti, 2015). Whether the protocols used active dynamic stretching, static dynamic stretching, or a combination, did not appear to impact effectiveness. A dynamic warm-up programme including callisthenics improved quadriceps but not hamstrings peak torque, speed, jumping ability, and muscular endurance in adult wrestlers (Herman & Smith, 2008). Gymnastics-specific dynamic warm-ups, including slow dynamic ROM exercises (Ferri-Caruana et al., 2020) and more dynamic activities (Ahmadabadi et al., 2015), can be a valuable addition to gymnastics training regimes in junior athletes to improve ROM and induce large effect size improvements in isometric strength (Ferri-Caruana et al., 2020), and some improvements in balance (Ahmadabadi et al., 2015). In most cases, dynamic stretching or dynamic warm-up added some value to the training regime with multiple studies reporting large effect size improvements in some but not all variables.

Combination stretching protocols

Combination stretching protocols were included in three studies with some beneficial effects seen in two studies (Donaldson, 2010; Wilson et al., 1992), and non-significant effects in the final study (Álvarez-Yates & Garcia-Garcia, 2020). Kicking distance in adult Australian rules football athletes significantly improved from two minutes of daily hamstrings static and dynamic stretching (Donaldson, 2010). Loaded and unloaded static and dynamic stretching targeting the pectoralis-deltoid complex led to an average 7.2 kg significant improvement in maximal rebound bench press and non-significant 5.3 kg improvement in purely concentric bench press (Wilson et al., 1992). The non-stretching control groups lacked any significant performance changes in both studies. In junior canoeists, a supervised lower body and trunk programme combining contract relax proprioceptive neuromuscular facilitation, dynamic stretching and static stretching improved the ROM of the lower back and hamstrings with a concurrent increase in muscle stiffness and lateral symmetry of the hamstrings. However, performance improvements in concentric leg press did not reach significance and a lack of a comparable level control group limits the conclusions that can be drawn (Álvarez-Yates & Garcia-Garcia, 2020). The exact timing of the interventions was not always clear, details provided included daily application (Donaldson, 2010), post-weight training (Wilson et al., 1992), or integrated into the periodized training plan (Álvarez-Yates & García-García, 2020). Research on combining stretching protocols is limited and effect size changes vary from trivial to large.

Exercise movement techniques: Yoga, Pilates & dance

Twelve studies assessed sports or muscle performance after yoga, Pilates, or dance exercises conducted two to three times per week for three to 10 weeks. The mobility programmes tended to utilise the full body, one study focusing on hip joint flexion (Arihiro et al., 2018), and another lower body and trunk (Da Cruz et al., 2014). Six studies investigated yoga with three showing performance improvements (Biswas et al., 2021; Polsgrove et al., 2016; Rao et al., 2021), and two indicating yoga may maintain performance and avoid performance declines, when added to routine training (Holt, 2016; Raj et al., 2021). The final study found yoga to provide large performance improvements on par with a sports-specific control programme including medicine ball slams and bowling drills (Vaidya et al., 2021). Overall, yoga appears of some benefit to field team sports. Soccer players experienced a moderate improvement in static balance (Polsgrove et al., 2016), softball players maintained their relative stride length (stride length relative to standing height) (Holt, 2016), rugby players maintained their speed (Raj et al., 2021), and cricket players improved a range of attributes including aspects of strength, jump performance, balance, COD and bowling performance, with many of the improvements of large effect (Biswas et al., 2021; Rao et al., 2021; Vaidya et al., 2021).

Pilates training was the focus of four studies of which two suggested beneficial effects (Arihiro et al., 2018; El-Sayed et al., 2010), and two possible benefits (Da Cruz et al., 2014; Greco et al., 2019). All studies investigated the effect of adding Pilates to routine training, however one study lacked a control group (El-Sayed et al., 2010). Jumping ability was improved with Pilates in adult volleyball players (El-Sayed et al., 2010). Sports-specific tests were also improved in adult rugby and volleyball players (Arihiro et al., 2018; El-Sayed et al., 2010). Two studies lacked significant between-group performance changes (Da Cruz et al., 2014; Greco et al., 2019); however, within-group improvements were significant in one study (Greco et al., 2019), and both studies saw medium to large effect sizes improvements in countermovement jump (CMJ) performance. Most studies appeared to use Pilates as a cross-training session and exercises programme varied in their focus of either full body or lower body and trunk. Arihiro et al (Arihiro et al., 2018) scheduled Pilates before weight training and focused on hip joint flexion exercises.

Two studies utilized dance as a form of mobility training and found some consequent improvements in muscle and sports performance (Alricsson et al., 2003; Solomons et al., 2021). Speed and agility improved in junior cross-country skiers with small and moderate effect sizes respectively (Alricsson et al., 2003). Upper body power and muscular endurance were improved in rugby players (Solomons et al., 2021). Further positional-specific improvements were found in certain fitness variables, although time and treatment order effects appeared to have some influence on the results. The timing of the interventions in the training schedule was not entirely specified, although Solomons et al (Solomons et al., 2021). indicated it was part of the weekly schedule and not an additional session. The exact dance exercises were not specified but were likely using the full body with a potential bias towards the lower body.

Performance outcomes

Strength-related tasks

Strength-based measures were assessed in nine studies, with six studies noting some improvements following mobility training (Biswas et al., 2021; Ferri-Caruana et al., 2020; Herman & Smith, 2008; Rao et al., 2021; Solomons et al., 2021; Wilson et al., 1992), two with non-significant findings (Álvarez-Yates & Garcia-Garcia, 2020; Holt, 2016) and one showing a significant large effect size improvement on par with a sports-specific control intervention including medicine ball slams and bowling drills (Vaidya et al., 2021). Two studies assessed hamstrings and quadriceps strength via isokinetic dynamometry (Herman & Smith, 2008; Holt, 2016). Yoga demonstrated no effect on the dynamic control ratios of the knees at $300°.s^{-1}$ in softball players (Holt, 2016). A dynamic warm-up including callisthenics style exercises improved concentric quadriceps but not hamstrings peak torque (Herman & Smith, 2008).

Strength tests such as the horizontal leg press or bench press indicated that mobility training is more likely to have a positive effect on performance when testing includes both the eccentric and concentric phase (Álvarez-Yates & Garcia-Garcia, 2020; Wilson et al., 1992). Field tests of muscular strength, endurance and power generally showed improvements when the tests reflected movement patterns in the mobility interventions (Ferri-Caruana et al., 2020; Herman & Smith, 2008), and core strength typically improved following yoga (Biswas et al., 2021; Rao et al., 2021).

Jumping ability

Jumping ability, predominantly assessed via vertical jump, CMJ, squat jump, or broad jump, was assessed in nine studies (Da Cruz et al., 2014; El-Sayed et al., 2010; Ferri-Caruana et al., 2020; Greco et al., 2019; Herman & Smith, 2008; Solomons et al., 2021; Sudhakar & Padmasheela, 2012; Turki-Belkhiria et al., 2014; Vaidya et al., 2021). Two of three studies demonstrated a clear benefit of dynamic stretching or dynamic warm-up over more traditional methods such as static stretching for improvement in jumping ability (Herman & Smith, 2008; Sudhakar & Padmasheela, 2012). In five studies mobility training was comparable to routine training for improvement in jump performance, although the effect size change after mobility training were typically greater than controls (Da Cruz et al., 2014; Ferri-Caruana et al., 2020; Greco et al., 2019; Sudhakar & Padmasheela, 2012; Vaidya et al., 2021). El-Sayed et al (El-Sayed et al., 2010) reported large improvement in jump performance following Pilates, although no control group was used for comparison. Jumping ability remained unchanged in rugby players following dance training, however the routine training control comparison experienced a significant performance decrease in the second time block in their crossover experimental design (Solomons et al., 2021). Across the studies CMJ saw the most improvements with large effect sizes in almost all cases. SJ performance tended to improve to a lesser degree with small to moderate improvements. While there is no evidence that mobility training may be harmful to jump performance, stronger evidence is required to advocate the use of mobility training solely for the purpose of maximising jump performance.

Speed-related tasks

Five studies included measures of linear speed with two showing some improvements (Alipasali et al., 2019; Herman & Smith, 2008) and three studies with non-significant changes (Biswas et al., 2021; Raj et al., 2021; Turki-Belkhiria et al., 2014), two of which demonstrated a reduction in speed in control athletes performing routine training (Raj et al., 2021) or no stretching (Turki-Belkhiria et al., 2014). Short-distance sprint performance as required by many team sports (4.5–35 metres) was improved or maintained (Alipasali et al., 2019; Raj et al., 2021; Turki-Belkhiria et al., 2014) following mobility training. In terms of COD or speed performance combined with obstacles, three studies reported some improvements with typically small to moderate effect sizes (Alricsson et al., 2003; Biswas et al., 2021; Herman & Smith, 2008), and two studies reported non-significant findings (Da Cruz et al., 2014; Taleb-Beydokhti, 2015), one of which avoided a significant decline in the static stretching control comparison (Taleb-Beydokhti, 2015). (Solomons et al., 2021) demonstrated more improvements in COD performance following the control period of routine training, with variations according to playing position and treatment order. More evidence is required to clarify the effect of mobility training on speed and COD tasks, but there appears some evidence that a lack of mobility training may lead to a decline in performance.

Balance

Five studies assessing balance demonstrated some improvements following mobility training seen in the stork stand test (Biswas et al., 2021; Polsgrove et al., 2016; Rao et al., 2021), Y balance test (Rao et al., 2021), star excursion balance test (Vaidya et al., 2021) and double-leg static and dynamic balance (Ahmadabadi et al., 2015). Solomons et al (Solomons et al., 2021) found some balance improvements which appear more related to the time period than the intervention itself. In gymnastics, balance is a key technical requirement performed in combination with flexibility skills (Ahmadabadi et al., 2015). Consequently, Ahmadabadi et al (Ahmadabadi et al., 2015) found a dynamic mobility warm-up improved double-leg, but not single leg balance, in conjunction with vault performance. Soccer and cricket were the other sporting groups which improved balance following mobility training (Biswas et al., 2021; Polsgrove et al., 2016; Rao et al., 2021).

Sports-specific skills

Seven studies included sports-specific assessments with generally positive outcomes. Squat mechanics (Arihiro et al., 2018), block and attack performance (El-Sayed et al., 2010), gymnastics vault (Ahmadabadi et al., 2015), and bowling performance (Vaidya et al., 2021) were improved with mobility training with large effect sizes. Drop punt kicking distance was improved in Australian rules football by 4.1 metres (Donaldson, 2010). Six weeks of yoga did not alter four aspects of throwing kinematics, although it did avoid a significant decrease in relative stride length that was experienced by routine training alone (Holt, 2016). It was also reported that 84.61% of participants found yoga helped facilitate physical relaxation post-workout (Holt, 2016). While there was a lack of significant improvement in split leap flight time in rhythmic gymnasts, there was a trend for improvement with the slow dynamic ROM protocol which demonstrated a large effect size change (Ferri-Caruana et al., 2020). In recreational cricket players, both a yoga intervention and a sports-specific bowling intervention produced similar large effect size improvements in bowling performance (Vaidya et al., 2021).

Discussion

To determine if mobility training should be an integral part of an athlete's conditioning programme, the current review examined the effect of mobility training studies on sports performance. Overall, the inclusion of mobility training provided some benefit to sports in maintaining or improving the current performance level (six dynamic stretching or dynamic warm-up, two combination stretching, six yoga, four Pilates and two dance interventions). Two studies had no impact on performance (one dynamic stretching or dynamic warm-up, and one combination stretching study). In no instances did mobility training lead to a performance decline. Common attributes of the mobility training modalities which may account for the results seen include exercises through full range of motion, isolated core work, and rehearsal of sports-specific movement patterns.

Mobility protocols

Dynamic stretching

Rehearsal of sport-specific movement patterns is a proposed mechanism for acute performance improvements following dynamic stretching (Opplert & Babault, 2018), which may also impact longer-term adaptions. Interventions including dynamic stretching or dynamic warm-ups tended to include exercises that are also technical drills and skill rehearsal for running and jumping including; knees to chest, heels to bottom, lunge exercise variations (Ahmadabadi et al., 2015; Alipasali et al., 2019; Herman & Smith, 2008; Sudhakar & Padmasheela, 2012; Turki-Belkhiria et al., 2014), and plyometric drills (Ahmadabadi et al., 2015; Herman & Smith, 2008). Performing mobility drills whilst travelling or without support also added a balance component to the exercises (Sudhakar & Padmasheela, 2012; Turki-

Belkhiria et al., 2014). Sport-specific actions such as leg swings in kicking sports (Donaldson, 2010), loaded and unloaded upper body mobilizations for powerlifting (Wilson et al., 1992), and straight leg raises and isometric holds in rhythmic gymnastics were also programmed to optimize sports performance (Ferri-Caruana et al., 2020). Improvement in neuromuscular coordination from regular dynamic stretching and dynamic warm-ups incorporating sports-specific movements may explain some of the improvements seen.

Combination stretching

Despite many coaches using a combination of techniques in their warm-ups (Behm, 2018), combination stretching has received little research attention. However, the ability to combine different stretching techniques has been used in dance and gymnastics to allow optimal development of ROM and then to potentiate the muscles to perform the dynamic movements of the discipline (Skopal et al., 2020). Two studies from our review provide support for combining static and dynamic stretching to improve dynamic sports movements such as kicking and rebound bench press. The static stretching component of the programme may have served to improve range of motion, while the dynamic stretching component allowed the athletes to practice utilising their full range of motion at speed.

Exercise movement techniques: Yoga, Pilates & dance

Many of the mobility protocols, especially the yoga and Pilates interventions, included a range of spine mobilizations through flexion, extension and rotation. Optimal spine mobility, particularly of the thoracic spine, allows an athlete to maximise force transferred through the kinetic chain (Heneghan et al., 2020). For example, spine and wrist flexibility are associated with increased ball velocity in fast bowling (Sisodia, 2017). Three yoga studies in the current review included cricket players (Biswas et al., 2021; Rao et al., 2021; Vaidya et al., 2021), with one of the three studies directly measuring bowling performance (Vaidya et al., 2021). Yoga was equally effective in improving bowling speed and accuracy as a sports-specific intervention including a range of medicine ball slams and bowling drills. Since bowling places a high level of stress on the body (Sisodia, 2017), having an alternative cross-training modality, which also improves performance could be advantageous for load management.

Hamstrings flexibility developed through yoga may also be important to the optimal performance of sports skills (Holt, 2016). Athletes amid a busy softball competition season, who were not engaged in yoga experienced an average 5.7 degree decrease in passive knee extension and a 4.8% decrease in relative stride length, equivalent to 7.98 cm (Holt, 2016). Biomechanical analysis of pitching supports the notion that flexibility of the hip joint is related to stride length and throwing performance (Albiero et al., 2022) instead found that hip extension, rather than hip flexion range of motion was moderately positively correlated to stride length. Due to the positive relationship between stride length and throwing velocity (Albiero et al., 2022), lower body, mobility training appears an essential component in overhead throwing sports.

Hip mobility can also be optimised from Pilates which typically includes active movements through hip flexion, extension, abduction, adduction, rotation and circumduction. Arihiro et al (Arihiro et al., 2018) found deep squat depth to improve in athletes completing Pilates before weight training. Core (trunk) strength or endurance would also be expected to improve following Pilates, however this outcome measure was not included in the Pilates studies reviewed. It was, however, shown to improve with yoga (Biswas et al., 2021; Herman & Smith, 2008; Rao et al., 2021; Vaidya et al., 2021). Previous research suggests the addition of core training to routine sports training has small benefits to lower body power (relevant to jump performance) and maximal strength, and moderate benefits to linear sprint speed, COD, and sport-specific skills in swimming, handball, tennis and soccer (Saeterbakken et al., 2022). Basketball, karate, muay thai, gymnastics, volleyball, badminton and golf skills have all previously improved as a result of core training (Luo et al., 2022). Therefore, mobility interventions including a significant proportion of core exercises, such as Pilates and yoga, may have impacted performance in part by improving the ability to stabilize the lumbo-pelvic hip complex, limiting excessive trunk displacements during athletic tasks.

Similar to yoga and Pilates, dance training can also benefit spine mobility. Alricssion et al (Alricsson et al., 2003) found a nine-degree improvement in flexion-extension range of the lumbar and thoracic spine, as well as improvement in lateral flexion of the lumbar spine but not rotation of the thoracic spine. Therefore, it can be speculated but not confirmed that improved ROM contributed to speed and COD performance improvements seen in cross-country skiers by improving movement mechanics. The other dance inspired mobility intervention was specifically designed with the sport requirements and movement patterns in mind (Solomons et al., 2021); therefore, the movement rehearsal benefits and improvement in coordination often experienced from dynamic stretching may also relate to dance training interventions if appropriately designed for the sporting population.

Whether the reported improvements from the various exercise movement techniques in this review were attributable to changes in ROM or other related effects of mobility training cannot be certain, as not all studies reported changes in ROM. Of the studies that did report ROM changes in addition to performance outcomes, 65% reported significant improvement in at least one ROM assessment following intervention. The most common ROM assessments included variations of the sit and reach test, knee or hip flexion and/or extension tests, and a range of other shoulder and spine ROM tests, with only a few studies measuring mobility in sports-specific positions. The most commonly reported sit and reach test has limited validity in estimating flexibility, particularly of the lumbar spine, and to a lesser degree of the hamstrings (Mayorga-Vega et al., 2014). The only study to comprehensively measure changes in spine ROM was Alricssion et al (Alricsson et al., 2003) following dance training, Therefore, it can be speculated but not confirmed that improved ROM contributed to performance improvements in the current review.

Choice of mobility training modes

The choice of mobility training mode is an important consideration which will depend on several factors including whether the coach is looking for a purely physical, or both a physical and psychological outcome from the training session. For example, yoga and Pilates are well established as mind-body practices, whereas dynamic or combination stretching are typically used more for the physical adaptions. Yoga, Pilates and dance training typically require a suitably qualified instructor, which may require additional budget. Acceptance or interest from the athletes in trying a particular method may also influence effectiveness. It is difficult to argue one method over another when there can be so much diversity even within the same method depending on the exercises chosen. Therefore, it is recommended that the coach takes into consideration the goals of the sport and any gaps in the existing training programme when selecting an appropriate mobility training mode and curating the intervention.

Timing of the interventions

The timing of mobility training in the weekly schedule is another consideration for physical preparation coaches. Most dynamic stretching or dynamic warm-up studies incorporate their interventions in the warm-up for another session, which appears time efficient. Mobility exercises pre-training have been suggested as an effective motor learning strategy for athletes, allowing them to apply the movement strategy in the subsequent session (Brooks & Cressey, 2013). Some studies did not specify the timing of the intervention but included statements such as daily (Donaldson, 2010), administered individually (Alipasali et al., 2019), in the morning before any other activity (Polsgrove et al., 2016) or incorporated in the periodized or weekly training plan (Álvarez-Yates & Garcia-Garcia, 2020; Solomons et al., 2021). Some interventions appeared to be a separate cross-training session, although this was not always explicitly stated (Alricsson et al., 2003; Da Cruz et al., 2014; El-Sayed et al., 2010; Vaidya et al., 2021).

Providing recommendations as to the timing of mobility training would be highly dependent on the existing training schedule. Shorter bouts up to 15 minutes were typically used in a warm-up or cool down, or slightly longer in sports such as gymnastics, which tend to require longer warm-ups. Yoga and Pilates interventions ranged from 20 to 80 minutes. The lower end of that range may suggest suitability as a preparatory or cool down session, whereas a longer intervention might be more suitable as a physical and mental cross-training session on a day off. The two dance interventions were 60 minutes plus, suggesting suitability as a cross-training session unless the interventions are condensed. Overall, the most important factor is that dynamic mobility training is factored into the periodized training programme, which was indicated as the case in most of the interventions.

Performance outcomes

Strength

There were a large range of strength-related outcome measures used amongst the reviewed studies, making them challenging to compare. The strength profiles of the hamstrings and quadriceps are relevant to sports that depend upon sprinting, rapid change of direction, jumping, and throwing (Donaldson, 2010). Two studies (one dynamic warm-up, one yoga) investigated hamstrings and quadriceps strength via isokinetic dynamometry. The results found no effect on hamstrings strength and a possible effect on quadriceps strength when muscular endurance was targeted due to a prescribed slow cadence of movements (Herman & Smith, 2008; Holt, 2016). Neither study assessing peak torque of the hamstrings and quadriceps improved ROM, suggesting the interventions may have not been sufficiently designed for this purpose. Conversely, a 13.1% improvement in glenohumeral ROM and a 7.2% decrease in musculoskeletal stiffness following combination stretching had greater effect of rebound rather than purely concentric bench press (Wilson et al., 1992). This supports the notion that mobility training is more likely to influence strength tasks involving an eccentric phase. Since muscle contractions in sports rarely occur in isolation, examining the full contraction cycle is important to produce relevant performance data.

Jump performance

Results from jump performance also indicated greater improvements in CMJ (which includes an eccentric phase before take-off), than a squat jump (which begins with the concentric phase). The effect of mobility training on jump performance and other performance variables may be mediated by the contact time for the activity. A jump performed with a long stretch-shortening cycle (SSC) >250 ms, may benefit from a more compliant muscle-tendon complex, whereas a jump requiring a shorter SSC may not (Behm, 2018). It is important to note that although a more compliant muscle is often also more flexible this is not always the case (Behm, 2018). It is possible to train a muscle to have a high stiffness and rapid SSC but also high tolerance to stretch and ease of extensibility. This highlights the need for the ideal development of strength, flexibility, and mobility for athletic performance, which is likely task dependent.

Speed and change of direction

Speed and change of direction ability are complex psychomotor sports skills which are related yet independent (Kamioka et al., 2016). A mobility training programme targeting movement mechanics, core strength and coordination may have the ability to improve or maintain linear speed and or change of direction. The current review saw a mix of studies with some improving speed-related performance versus others maintaining performance over time. This may be related to minor programming differences. Three dynamic stretching studies utilised similar movements, however, Alipasali et al (Alipasali et al., 2019) additionally set a stretch intensity of maximum ROM without pain. This may have been important for setting the intention or pace of movement amongst the athletes. Other studies either did not specify an intensity (Herman & Smith, 2008; Turki-Belkhiria et al., 2014) or made vague statements such as intensity progressed from moderate to high intensity (Taleb-Beydokhti, 2015).

If core strength is a moderator for COD tasks, which require quick transfer of bodyweight, yoga and Pilates would be expected to improve performance. However, while one yoga study improved COD performance (Biswas et al., 2021), another Pilates study did not (Da Cruz et al., 2014). A dance intervention was successful in improving speed in slalom and hurdle performance tests concurrent with improvements in passive hip ROM (Alricsson et al., 2003). Dance interventions are typically performed to music which can also help to set the pace of movement, rather than being self-selected. More research is required to decipher the ideal programming variables for speed-related performance. However, the ability to maintain performance during a busy training or competition period should not be overlooked, since it is not realistic to acquire performance improvements all year round.

Mobility training may also play a role in maintaining ROM requirements for efficient sprint mechanics. Turki-Belkhiria et al (Turki-Belkhiria et al., 2014) found a moderate decline in 20-metre sprint performance as a result of routine training versus a moderate improvement in soccer athletes performing active dynamic stretching exercises. Similarly, Raj et al (Raj et al., 2021) found a large 14.8% decline in flexibility, coinciding with a 4.4% decline in 30-metre sprint performance from routine rugby training. However, yoga enabled athletes to maintain their ROM and speed in both the soccer and rugby studies. Only a handful of studies have investigated the relationship between ROM, sprint mechanics and speed. Biomechanical analysis of sprinters suggests that adequate hip ROM, particularly hip flexion is important for maximising speed, as it allows for a quicker heel recovery, longer stride length, and a reduction of braking forces at heel contact (Bushnell & Hunter, 2007). Utilizing complete ankle dorsi-plantar flexion ROM has also been found to be critical to attain maximum velocity for short-distance sprint performance in team sports (Struzik et al., 2015).

Balance

Although balance is more often associated with injury prevention, research is beginning to assess the potential links between balance and sports performance (Balyi et al., 2016; Büssing et al., 2012; Da Cruz et al., 2014; Page et al., 2021). Impaired balance or instability can adversely affect strength and power output (Anderson & Behm, 2004; Behm & Anderson, 2006). Poor balance is also related to poor flexibility and muscle imbalances (Biswas et al., 2021). All five studies measuring balance demonstrated some improvements following mobility training (one dynamic warm-up, three yoga, one dance intervention) (Ahmadabadi et al., 2015; Biswas et al., 2021; Polsgrove et al., 2016; Rao et al., 2021). One study improved double leg, but not single leg balance; however, the intervention did not include unilateral exercises (Ahmadabadi et al., 2015), highlighting the importance of programming specificity. Whether the improvements seen in common balance tests translate to improvements in the rapid adjustments required to dynamically stabilise in sport requires further investigation. The results of Ahmadabadi et al (Ahmadabadi et al., 2015) suggest it may be possible in the case of gymnastics vault performance. Overall, the current review demonstrates that mobility training can be programmed to not only optimize ROM but also challenge balance.

Review strengths and limitations

This is the first review to systematically analyse the influence of mobility training in purely sporting populations. This review also included studies with junior athletes. The relatively small sample sizes and potential risk of bias affecting the reviewed studies should be considered as a limitation. Although in scientific research, randomized control trials are desirable, this presents several challenges within a high-performance sporting environment. Often the sporting populations cannot be randomly selected, controlling all other aspects of the training environment is challenging and withholding a potential performance enhancing intervention from a sub-group of that population might not be ethical (Bishop, 2008). Although broad in nature, this review is an appropriate starting point from which further research on mobility training in sports can be developed. Apart from one study which persisted for eight months (Alricsson et al., 2003), the mean intervention duration was only 6.6 weeks or 21 sessions. Therefore, only short- to medium-term effects of mobility training can be summarised. Therefore, this review sought to summarise the available evidence, in the appropriate contexts relevant to applied sports settings.

Future directions

Future research should continue to investigate the effects of mobility training in defined sporting populations so that more specific recommendations can be made. The inclusion of a non-stretching control group where possible is also advised when comparing multiple mobility methods as well as using commonly researched performance measures of strength, power, speed, COD, and balance. When comparisons are being made to routine training, any existing elements of training schedule including mobility or stretching should be indicated. The timing of the intervention in relation to the existing training schedule should be identified as either pre-training, post-training or a separate cross-training session. Changes in ROM should be monitored to help evaluate the effectiveness of implemented mobility protocols. Detailed description of exercises and prescription variables including figures will assist comparison between studies. Biomechanical analysis of sports skills following mobility training would provide a valuable contribution to the field.

Conclusions

The available evidence suggests that a range of mobility training methods can help or at least are unlikely to hinder the development of key sports performance variables in both youth and adult athletes. While fitness-specific training methods should remain, mobility training often has synergistic effects in improving many performance-related attributes with small to large effects on strength, speed, jumping ability, balance, and sports-related skills. As caveats, research is generally of moderate to low quality lacking large sample randomized controlled trials. While conclusions generally support positive outcomes, there are some inconsistencies and therefore the coach should always consider the needs of the sport when prioritising the prescription of fitness attributes.

Practical applications

For those seeking to affect sports performance with mobility training some recommendations are provided below. Regular mobility training with a minimum of two to three times per week appears to be more important than volume per session. Periodization and monitoring can be implemented alongside other aspects of the training programme. A variety of methodological approaches to mobility training can be effective. Exercise movement techniques such as yoga, Pilates, and dance exercises are a cross-training option as well as more traditional methods such as dynamic stretching. Exercises relevant to the movement patterns of the sport are recommended for transfer to sports performance. Monitoring ROM changes throughout the programme will be important to ensure its effectiveness. In conclusion, high-performance coaches may consider including comprehensive mobility programmes in the weekly training schedule as a cross-training session and/or as part of complete warm-ups and cool-downs in a balanced athletic preparation programme.

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