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SYSTEMATIC REVIEW

The Use of Acute Exercise Interventions as Game Day Priming Strategies to Improve Physical Performance and Athlete Readiness in Team-Sport Athletes: A Systematic Review

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Abstract

Background The use of exercise as a priming strategy to enhance sport performance is becoming increasingly popular in professional sports and as an area of research interest. Early research suggests that the acute physiological responses to exercise can positively influence performance for up to 48 h. There is yet to be a comprehensive review of exercise strategies which could be implemented specifically on the day of competition.

Objectives The aim of this systematic review was to provide a synthesis of research investigating acute exercise interventions as game day priming strategies for team-sport athletes to improve physical performance and athlete readiness when implemented in the 1–12 h prior to competition.

Methods A literature search of SPORTDiscus, PubMed and Cochrane Central Register for Controlled Trials was conducted. A total of 6428 studies were retrieved and assessed against the following inclusion criteria: (1) randomised controlled trials and non-randomised comparative studies with reported pre–post intervention outcomes; (2) exercise interventions were applied 1–12 h prior to the assessment of outcome measures. Studies were excluded if they used nutrition, supplementation, pre-heating, pre-cooling, stretching, massage or vibration training as the priming strategies, or if interventions were performed at altitude or in hypoxic environments. Studies were assessed for methodological quality at the study level using the Physiotherapy Evidence Database (PEDro) scale.

Results Twenty-nine studies satisfied the eligibility criteria and were included in this review. Studies were categorised as resistance training; cycling; running; and other strategies. Resistance training using heavy loads at low volumes increased strength and power measures following a 4–6 h recovery, with limited improvements observed following shorter (1–3 h) and longer (6–12 h) recovery periods. Running-based sprint priming led to improvements in subsequent sprint and repeat sprint performance following a 5–6 h recovery, whereas cycling improved counter-movement jump height in a single study only. No significant differences were reported in any performance measures following endurance-based running or cycling strategies. Physiological markers, such a hormone and blood lactate responses, showed mixed results between studies.

Conclusions High-intensity low-volume resistance training leads to a greater physiological and performance response than high-volume resistance training. Maximal running sprints may be more effective than maximal cycling sprints due to an increased physiological demand; however, loading protocols must also be considered in conjunction with exercise volume and movement specificity to achieve a beneficial response for subsequent performance. There is limited evidence to suggest endurance cycling or running exercise is beneficial as a priming strategy.

1 Introduction

Team sports often require athletes to complete sport-specific tasks alongside repeated maximal or near maximal efforts (e.g. accelerating, decelerating, sprinting, jumping, and changing direction) that are interspersed with brief recovery periods [1]. Contact sports, such as Rugby codes, also require high levels of strength to successfully execute tackles or fend off opponents, compete for position, or play through

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Key Points

Low-volume resistance training performed with moderate to high loads and maximal intended velocity improved resistance-based strength and power performance in the subsequent 2–6 h.

Running sprints elicited greater improvements in subsequent 20–40 m sprint performance than cycle sprints and resistance training after a 5–6 h recovery.

Specific movement patterns performed under load appear to be more effective at improving subsequent performance of similar movements than general non-specific exercises.

contact [1, 2]. These demands rely heavily on the body's neuromuscular system to produce large force outputs and high-velocity movements [3]. As a result, sport performance practitioners spend much of their time implementing training and recovery strategies in the week leading into a match to ensure athletes are prepared for competition. However, recent research has identified an additional opportunity in the 1–12 h prior to competition in which 'priming' exercises, such as resistance training (RT), running and cycling, may be implemented with the aim of further improving physical performance and athlete readiness [4–7].

A majority of competition preparation occurs either chronically through the implementation of training strategies such as RT, or acutely through the use of a warm-up. An increase in strength and power qualities through ongoing RT has been shown to transfer to athletic performance through improvements in jump performance, speed and acceleration, and change of direction ability in a range of team-sport athletes [8–10]. Warm-ups are often implemented within 1 h of competition and assist in the expression of the aforementioned qualities primarily due to increases in muscle and core temperature [11, 12], which leads to an increase in neuromuscular conduction rates and increased blood flow to the muscles [12]. Whilst a combination of chronic and acute strategies such as RT and warm-ups is commonly used to improve performance [8, 9, 11, 12], an additional window of opportunity to further enhance performance is present in the 1–12 h prior to the start of competition. Kilduff et al. [6] suggested a number of preparation strategies for the day of competition to improve performance, including post-activation potentiation, hormonal priming, passive heat maintenance, active warm-up, remote ischemic conditioning, and morning RT. The aforementioned strategies all typically take place within 1 h of competition, with the exception of morning RT.

Morning RT has demonstrated performance improvements in afternoon strength and power activities. Ekstrand et al. [13] reported a 3.6% ($p < 0.01$) improvement in backwards overhead shot throw (BOST) performance 4–6 h after morning high-intensity RT, whereas Cook et al. [14] reported improvements in counter-movement jump (CMJ) peak power (2.7%, $p < 0.001$), upper-body strength (3.6%; $p < 0.001$), lower-body strength (4.2%; $p < 0.001$) and 40 m sprints (1.3%; $p < 0.001$), 6 h after morning high-intensity RT when compared to morning sprints and a controlled trial. Changes stemming from morning RT are not limited to performance markers, with changes in testosterone and cortisol concentrations in the hours following morning RT also reported [14, 15]. These two biomarkers follow circadian patterns with concentrations at their highest in the morning before declining across the day [14, 16, 17], and have previously been reported to influence physical performance in elite athletic populations [7, 14]. Interestingly, early research in priming reported that morning RT and sprints appeared to slow the circadian decline in testosterone and cortisol when compared to a controlled trial [14]. The changes in testosterone observed after morning exercise were reported alongside improvements in afternoon strength and power performance; however, the authors noted that the relationship is not causal, and that testosterone may simply be a reflective marker of athlete readiness [14]. Still, these findings suggest that changes in biomarkers could potentially contribute to improvements in competition performance following morning exercise.

The findings from the aforementioned studies highlight the potential benefits of priming for team-sport athletes [6, 14, 15]. These studies are further supported by a recent review investigating RT priming as a strategy for improving neuromuscular performance across a 48-h period [4]. Despite this, there is yet to be a comprehensive review of the implementation of acute exercise interventions as priming strategies on the day of competition. Therefore, the aim of this review is to synthesise the research examining acute exercise interventions to improve physical performance and athlete readiness. Due to the limited availability of applied research on the day of competition, this review will include exercise strategies that directly or indirectly influence performance and readiness markers in the 1–12 h following exercise.

2 Methods

2.1 Search Strategy

This systematic review was conducted in accordance with the guidelines from the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) [18]. The search strategy is outlined in Fig. 1.

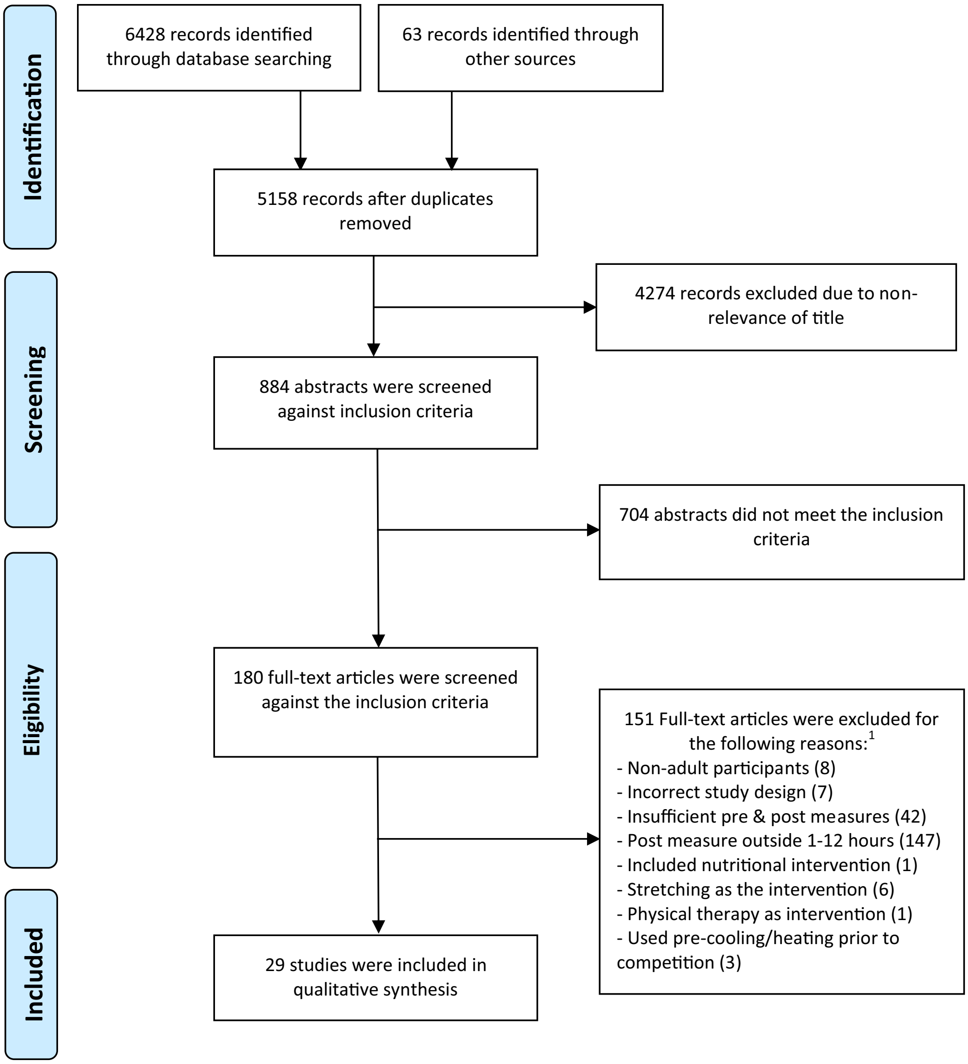

Fig. 1 Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) [18] study flow diagram. [1]Studies could be excluded for more than one reason

2.2 Literature Search

A computer search of Medline (PubMed), EBSCO Host (SPORTDiscus) and CENTRAL (Cochrane Central Register of Controlled Trials) was conducted through February 26, 2020. To ensure a comprehensive evaluation of available literature was undertaken, search terms were piloted and reviewed across each database. The variables in which data were sought were expanded to include terms referencing different sub-categories of each variables (see Table 1). The final Boolean searches were conducted using the terms: (resistance training OR strength training OR weightlifting OR run* OR cycl* OR sprint* OR jump*) AND (priming OR pre-activation OR prior exercise OR pre-conditioning OR warm-up) AND (read* OR prepar* OR compet* OR perform* OR game OR match OR sport OR strength OR power OR speed OR agility).

Table 1 Sub-categorical search terms used to ensure a comprehensive search of available literature was conducted

Exercise interventions	Priming strategy	Readiness/Performance
Resistance training; OR	Pre-conditioning; OR	Read*; OR
Strength training; OR	Pre-activation; OR	Prepar*; OR
Weightlifting; OR	Prior exercise; OR	Compet*; OR
Run*; OR	Priming; OR	Perform*; OR
Cycl*: OR	Warm-up	Game; OR
Sprint*; OR		Match; OR
Jump*		Sport; OR
		Strength; OR
		Power; OR
		Speed; OR
		Agility

The following restrictions were applied to the search:

1) studies written in English only
2) studies using human participants
3) peer-reviewed journal articles only
4) studies published prior to February 26, 2020

2.3 Inclusion and Exclusion Criteria

Two authors (BM, NB) separately and independently reviewed search returns for eligibility. Any discrepancies between the two reviewers were discussed between the authors until a consensus was reached, with unsettled differences resolved in consultation with a third author (AM).

Studies were eligible for inclusion in this review if they satisfied the following criteria:

1) participants had no known medical conditions and presented free from pain, injury, illness and disease;
2) participants were from a healthy adult population aged 18–40 years;
3) were randomised controlled trials and non-randomised comparative studies with reported pre–post intervention outcomes;
4) included an exercise intervention applied on the same day, from 1–12 h prior to the assessment of outcome measures.

Studies were excluded from this study if they included any of the following criteria:

1) assessed the effects of supplementation or nutrition on exercise;
2) exercise interventions were completed at altitude or in hypoxic environments;
3) stretching with no external resistance/load as the only exercise intervention;
4) vibration training was used as the exercise intervention;
5) massage was used as the intervention;
6) assessed the effects of pre-cooling or pre-heating prior to exercise.

The above criteria were selected due to the practicality for team sports, specifically targeting exercise strategies implemented with the aim of improving subsequent performance and readiness. By limiting the inclusion of alternative interventions, such as nutrition and supplementation, the effectiveness of exercise interventions alone could be assessed. Studies that fell within 1–12 h yet spanned overnight were excluded to negate the recovery effects of sleep [19]. The use of static or dynamic stretching with no external resistance, vibration training, massage and/or pre-cooling or pre-heating has not been included in this review as they are either (a) not classified as exercise, or (b) may have a confounding effect on the participant's response to exercise.

2.4 Data Extraction

Data were extracted by the lead author (BM) and included participant characteristics (e.g. sample size, sex, age, height, mass), study characteristics (e.g. exercise intervention, recovery), and a summary of findings (e.g. key outcome). After extraction, the information was reviewed in consultation with the second author (NB), and studies were grouped according to the exercise intervention used: (a) resistance training; (b) cycling; (c) running; and (d) other interventions, which were classed as interventions that did not fall into the previous categories or used a combination of the strategies. Studies which used more than one strategy were included in and reported on for all eligible sections.

2.5 Risk of Bias Analysis

Studies were assessed for methodological quality at the study level using the Physiotherapy Evidence Database (PEDro) Scale [20], which is a widely used tool to assess the methodological quality of randomised controlled trials in physical therapy studies [21, 22]. Total PEDro scores are reached based on satisfaction of criterion measures relating to participant allocation, allocation concealment, blinding of participants, therapists and assessors, and the provision of sufficient statistical information [21]. A total of 11 criterion measures are assessed; however, criterion 1 is to assess external validity and is not included in the total PEDro score [21, 22]. Therefore, a total score of 10 is attainable, which comprised the satisfactory reporting of criterion 2–11**.**

3 Results

Twenty-nine studies satisfied the eligibility criteria and were included in this review. Twenty studies implemented RT strategies: seven used cycling interventions; six assessed responses to running-based exercise interventions; and six implemented other interventions such as combined exercise strategies, jumping and boxing. Ten studies reported performance outcomes only; 12 studies reported physiological outcomes; and six studies reported both performance and physiological outcomes. Due to the variety of outcomes reported within each study and the potential to provide an indication of potential mechanisms involved, both performance and physiological responses in the 1–12 h following exercise are presented in this review.

3.1 Resistance Training Interventions

Resistance training was used in 20 studies with multiple volumes and intensities used within and between studies as shown in Table 2. Five studies used high-intensity training loads (> 85% 1RM) [13, 23–25, 27], 11 studies used moderate-intensity training loads (65–85% 1RM) [15–17, 24, 25, 27–32] and two used low-intensity training loads (< 65% 1RM) [31, 33]. Five studies used a range of training loads across low to high intensities within a single intervention [14, 33–36], whereas one study applied variable resistance using rubber bands [37]. There were no clear trends in exercise selection, exercise order or recovery periods across studies. The majority of studies used multiple exercises within the single RT session, with only three studies using a single exercise only [15, 31, 38]. The most commonly implemented exercises were the back squat (12 studies) and bench press (10 studies). Thirteen studies assessed responses to RT following 1–4 h of recovery, nine assessed responses >4–8 h after RT, and one study measured responses up to RT 11 h post intervention.

Increases in back squat (4.2%: $p<0.001$) and bench press (3.6%: $p<0.001$) 3RM loads, and BOST performance (2.6%; $p<0.01$) were observed 4–6 h after high-intensity RT in semi-professional rugby players and trained throwers, respectively [13, 14]. No differences in bench press or back squat velocity were observed 6 h post low-volume RT using 80% 1RM load in elite weightlifters (29). Similarly, no significant differences were observed in maximal isometric leg extensor force or rate of force development (RFD) 4 h post a high-intensity weightlifting session performed by elite weightlifters [35]. A significant reduction in peak torque at $60°.s^{-1}$ was observed in strength trained males at 3, 7 and 11 h post maximal intensity RT when compared with submaximal RT, which reported no change from baseline measures at the same timepoints [25]. Higher volume loads of 3×8 repetitions at 8RM in the bench press and back squat were associated with an 8.2% ($p=0.003$) decrease in the load required to elicit a movement velocity of $1.0\ m.s^{-1}$ (V_1-load) in the back squat, but no change in bench press V_1-load after 6 h, when compared with 3×4 repetitions using the same load in recreationally trained males [28]. Volume increases also negatively impacted peak force and RFD 2 h after high-volume leg extensions under two different loading conditions in untrained participants [31]. In contrast, the shorter recovery period between intervention and re-test led to increases in bench throw peak velocity (3.8%, $p<0.05$), power (8.5%; $p<0.05$) and force (13.9%; $p<0.05$), but not in loaded CMJ velocity, power or force, in academy rugby players following a 1 h and 45 min recovery from low-volume band-resisted exercises [37].

When using jump measures as performance indicators, the impact of the RT intervention was variable. One study showed an improvement in CMJ peak power (2.7%; $p<0.001$) 6 h after heavy back squats and bench press using 3RM loads [14] whereas another study reported a decrease in CMJ height (7.8%, $p=0.001$) 6 h after back squats and bench press performed using 3×8 at 8RM compared to 3×4 at 8RM [28]. Seven studies presented no significant differences in jumping performance under loaded and unloaded conditions in the 1–12 h following RT. A 5.5% ($p<0.05$) increase in drop jump (DJ) height was observed 6 h after an RT intervention with loads of 80–95% 1RM in trained volleyball players [33]. However, no change in DJ height following RT using loads of 30% 1RM was shown [33]. Under both DJ conditions, participants were instructed to jump for maximal height with minimal contact time, with height recorded as the performance measure [33]. RT was deemed to significantly improve only the early stages of repeat sprint performance (i.e. sprint 1 and 2 out of 6) in professional rugby players with no differences observed between the RT intervention and a controlled trial for subsequent sprints [15].

An increase in testosterone following moderate- to high-intensity RT was reported in one study [24], with four studies reporting decreases or no change when compared to pre-trial measures [14, 16, 24, 27]. When compared to controlled trials, moderate- to high-intensity RT led to increased salivary testosterone [14, 15], but not serum testosterone concentrations [16, 29, 30]. RT led to a decrease [14–16, 23, 27] or no changes [16, 29] in cortisol concentrations compared to pre-trial measures; however, higher cortisol concentrations were observed when compared to controlled trials [14, 29]. High-volume RT led to an increase in blood lactate 1 h post exercise [24, 27], with no changes from baseline after a 1.5 h recovery [23, 24, 29]. No differences were observed in mammalian target of rapamycin (mTOR) signalling pathways 1–3 h post RT [27, 34].

3.2 Cycling Interventions

Seven studies measured responses to cycling based interventions (see Table 3). Four studies measured responses to short duration maximal sprints (<30 s) using different set and repetition configurations [15, 39–41]. All four studies reported hormonal responses to exercise, whereas two assessed changes in CMJ height 1–5 h post exercise [15, 40]. These studies also assessed changes in repeat sprint ability (i.e. running) [15], reaction time [15], isometric knee extensor strength [40], and cycle sprint performance variables [40]. In addition to maximal sprint interventions, three studies implemented bouts of endurance exercise ranging from 24–65 min. Two studies assessed physiological responses to a 65 min maximum effort cycling intervention across a recovery period of 1–6 h [41, 42]. One study measured the influence of an incremental cycle test on running performance variables following a 5 h recovery [43].

Performance improvements stemming from cycling interventions were minimal. An increase in CMJ height (2.3%; $p<0.001$) was observed in professional male Rugby players 5 h after repeated cycle sprints, but not following a recovery period of 1 or 3 h in recreationally trained males [15, 40]. No changes were reported in mean or peak pedal rate or power output in a recreationally trained male population in the 1–4 h following maximal effort cycle sprints [40, 44]. No

Table 2 Summary of findings from studies using resistance training interventions (n = 20)

Study	Participants	Intensity	Stimulus	Recovery	Key outcomes
Apro et. al [27]	10 males; moderately trained Age: 26 ± 2 years Height: 179 ± 2 cm Mass: 85 ± 3 kg	65–85% 1RM	4 × 8–10 leg press (85% 1RM), 4 × 10–12 leg press (75% 1RM), 2 × sets to fatigue leg press (65% 1RM)	1 h/3 h	↔ Signalling of mTOR pathways^{a}, ↔ lactate at 3 h^{b}, ↓ 11% plasma glucose at 1 h^{b}, ↓ 6.4% plasma glucose at 3 h^{b}, ↑ 145.5% lactate at 1 h^{a}
Apro et. al [34]	8 males; > 6 months RT exp Age: 26 ± 2 years Height: 183 ± 2 cm Mass: 85 ± 2 kg	60–80% 1RM	4 × 8–10 leg press (80% 1RM), 4 × 10–12 leg press (70% 1RM), 2 × sets to fatigue leg press (60% 1RM)	1.5 h/3 h	↔ mTOR1 signalling following RT exercise at any timepoint^{a}
Bird & Tarpenning [16]	16 males; recreationally trained Age: 22.1 years Height: 176.9 cm Mass: 84.7 kg	75% 1RM	3 × 8–10 leg press, 3 × 8–10 leg curl, 3 × 8–10 leg extension, 3 × 8–10 shoulder press, 3 × 8–10 lat pulldown, 3 × 8–10 bench press, 3 × 8–10 bicep curl, 3 × 8–10 triceps extension (75% 1RM)	1 h	*Morning group*: ↓ 47% C 1 h post^{b}, ↓ 19% T 1 h post^{b}; *Evening group*: ↔ C 1 h post^{b}, ↔ T 1 h post^{b}
Cook et al. [14]	18 males; semi-professional rugby players Age: 22 ± 1 years Height: 184 ± 5 cm Mass: 93.7 ± 8.3 kg	80–100% 1RM	3 × 3 back squats (80%, 90%, 100% 3RM), 3 × 3 bench press (80%, 90%, 100% 3RM)	6 h	↑ 3.6% 3RM bench press^{c}, ↑ 4.2% 3RM back squat^{c}, ↑ 2.7% CMJ peak power^{c}, ↓ 1.3% 40 m sprint time^{c}, ↔ salivary T^{b}, ↑ salivary T^{c}, ↓ salivary C^{b}, ↑ salivary C^{c},
Ekstrand et al. [13]	14 (M 8; F 6); throwers with > 4 years' experience Age: 20.7 ± 2.5 years Height: 178.8 ± 11.0 cm Mass: 95.1 ± 26.9 kg	85–90% 1RM	1 × back squats to failure (85% of 1RM), repeated sets of 4 power cleans until failure (100% 4RM)	4–6 h	↑ 2.6% BOST^{c}, ↔ CMJ peak power^{c}
Gonzalez-Badillo et al. [28]	9 males; > 2 years RT exp Age: 23.3 ± 3.9 years Height: 175 ± 3 cm Mass: 75.3 ± 9.2 kg	~ 80% 1RM	3 × 4 back squats, 3 × 4 bench press (100% 8RM)	6 h	100.9% squat V$_{1}$-load^{b}, 100.8% bench press V$_{1}$-load^{b}, 99.3% CMJ height^{b}
		~ 80% 1RM	3 × 8 back squats, 3 × 8 bench press (100% 8RM)	6 h	↓ 8.2% squat V$_{1}$-load^{a}, ↔ bench press V$_{1}$-load^{a}, ↓ 7.8% CMJ height^{a}
Hakkinen et al. [29]	10 males; top-level Finnish strength athletes (powerlifters, body builders, weightlifters) Age: 29.7 ± 8.0 years Height: 178.2 ± 8.6 cm Mass: 82.4 ± 5.9 kg	100% 1RM	20 × 1 back squats (100% 1RM)	1 h/2 h	↔ free T, serum T, serum C at 1 h or 2 h^{b}, ↑ serum GH concentrations 1 h^{c}, ↔ serum GH 2 h^{c}, ↔ lactate^{b}
		70% 1RM	10 × 10 back squats (70% 1RM)	1 h/2 h	↔ free T or serum T^{b}, ↑ serum C^{c}, ↑ serum GH concentrations 1h^{c}, ↔ serum GH 2 h^{c}, ↔ lactate^{b}
Hakkinen et al. [35]	8; top-level Finnish weightlifters Age: 23 ± 3 years Mass: 70.3 ± 11.2 kg	70–100% 1RM	2 × 2 snatch (70%, 80% 1RM), 2 × 1 snatch (90%, 95% 1RM), 1 × 2–3 snatch (100% 1RM), 2 × 2 clean and jerk (70%, 80% 1RM), 2 × 1 clean and jerk (90%, 95% 1RM), 1 × 2–3 clean and jerk (100% 1RM), 2 × 2 front squat (70%, 80% 1RM), 2 × 1 front squat (90%, 95% 1RM), 1 × 2–3 front squat (100% 1RM), 1 × 3 front squat (85% 1RM)	4 h	↔ leg extensor maximal RFD^{b}, ↔ leg extensor maximal isometric force^{b}

Table 2 (continued)

Study	Participants	Intensity	Stimulus	Recovery	Key outcomes
Jensen et al. [30]	7 males; well trained Age: 25 ± 2.5 years Height: 179.9 ± 4.0 cm Mass: 74.7 ± 7.0 kg	80% 1RM	3 × 8 half squats, 3 × 8 bench press, 3 × 8 leg extensions, 3 × 8 behind the neck press, 3 × 8 weighted dips, 3 × 8 hamstring curls, 3 × 8 weighted chin-ups (80% 1RM)	2 h/4 h/ 6 h	↔ T concentrations at any timepoint ^{b,c}
Johnston et al. [23]	15 males; academy rugby players Age: 21 ± 1.0 years Height: 185.7 ± 6.6 cm Mass: 100.5 ± 10.5 kg	85% 1RM	5 × 4 back squats (85% 1RM), 5 × 4 Romanian Deadlifts (85% 1RM)	2 h	↔ CMJ height^{b}, ↔ CMJ peak power^{b}, ↔ T^{b}, ↓ 43.8% C^{b}, ↑ 19.5% creatine kinase^{b}, ↔ lactate^{b}, ↑ 78.1% muscle soreness^{b}
Kraemer et al. [17]	10 males; > 1-year RT experience Age: 21.6 ± 1.1 years Height: 177.8 ± 0.5 cm Mass: 80.5 ± 11.5 kg	~ 75% 1RM	3 × 10 hang pulls, 3 × 10 bench press, 3 × 10 leg press, 3 × 10 seated rows, 3 × 10 leg curls, 3 × 10 military press, 3 × 10 lat pulldowns, 3 × 10 leg extensions, 3 × 10 bicep curls (100% 10RM), 3 × 20 sit-ups	1 h/2 h/3 h/4 h	↔ salivary T concentrations at any timepoints^{a}, ↓ salivary T at each timepoint^{b}
Kraemer et al. [24]	9 males; healthy participants with RT experience Age: 24.7 ± 4.3 years Height: 178.4 ± 7.8 cm Mass: 81.1 ± 12.0 kg	~ 87% 1RM	5 × 5 bench press, 5 × 5 leg extension (100% 5RM), 3 × 5 military press, 3 × 5 bent-leg incline sit-ups, 3 × 5 seated rows (100% 5RM), 4 × 5 lat pulldowns (100% 5RM), 3 × 5 bicep curls (100% 5RM), 5 × 5 leg press (100% 5RM)	1 h/1.5 h/ 2 h	↔ Serum glucose or lactate at any timepoint^{b}, ↑ serum T at 1.5 h^{b}, ↔ serum T at any other timepoint^{b}
		~ 75% 1RM	3 × 10 bench press, 3 × 10 leg extension, 3 × 10 military press, 3 × 10 bent-leg incline sit-ups, 3 × 10 seated rows, 3 × 10 lat pulldowns, 3 × 10 bicep curls, 3 × 10 leg press (100% 10RM)	1 h/1.5 h/ 2 h	↔ Serum glucose at any timepoint^{b}, ↑ lactate at 1 h^{b}, ↔ lactate at any timepoint^{b}, ↑ serum T at 2 h post (session with rest control)^{b}, ↔ serum T at any other timepoint^{b}
Linnamo et al. [31]	16 (8 M; 8 F); physically fit, no RT or competitive sport exp Males; Age: 27.1 years Height: 181.3 cm Mass: 74.4 kg Females; Age: 23.3 years Height: 166.7 cm Mass: 59.9 kg	~ 75% 1RM	5 × 10 leg extensions (100% 10RM)	2 h	↓ 23.7% (males) and ↓ 18.8% (females) maximal peak force^{b}, ↓ 27% (males) and ↓ 28.9% (females) maximal RFD^{b}, ↓ 16.3% (males) and ↓ 11.5% (females) average force (0-100 ms)^{b}
		~ 30% 1RM	5 × 10 leg extensions (40% 10RM)	2 h	↓ 11% (males) and ↓ 12.1% (females) maximal peak force^{b}, ↓ 15.3% (males) and ↓ 11.6% (females) maximal RFD^{b}, ↓ 25.5% (males) average force (0-100 ms)^{b}, ↔ (females) average force (0-100 ms)^{b}
Mason et al. [37]	13 males; academy rugby players Age: 18.5 ± 0.5 years Height: 181.7 ± 6.8 cm Mass: 98.2 ± 16.9 kg	Variable	4 × 3 explosive back squats (band resisted), 4 × 3 explosive bench press (band resisted)	1 h 45 min	↑ 8.5% bench throw peak power^{c}, ↑ 3.8% bench throw peak velocity^{c}, ↑ 13.9% bench throw peak force^{c}, ↔ CMJ peak power^{c}, ↔ CMJ peak velocity^{c}, ↔ CMJ peak force^{c}, ↔ in readiness to perform^{c}

Table 2 (continued)

Study	Participants	Intensity	Stimulus	Recovery	Key outcomes
Palmer & Sleivert [32]	9 (M 5; F 4); well-trained runners with > 3 months RT exp Males: Age: 20.0 ± 1.1 years Height: 176.0 ± 4.3 cm Mass: 68.8 ± 6.6 kg Females: Age: 20.0 ± 1.1 years Height: 170.3 ± 10.7 cm Mass: 62.0 ± 11.0 kg	~ 80% 1RM	3 × 8 bench press, 3 × 8 squats, 3 × 8 upright rows, 3 × 8 deadlifts (100% 8RM), 3 × 15 of four different abdominal exercises	1 h/8 h	↓ peak torque 1 h post RT^{c}, ↑ submaximal VO_2 at 1 h (2.6%) and 8 h (1.6%)^{c}, ↔ heart rate, ventilation, RER, lactate, RPE, stride frequency or stride length^{c}
Raastad & Hallen [25]	10 males; powerlifters (8), javelin thrower (1), speed skater (1) Age: 27.5 ± 1.4 years Mass: 84.5 ± 4.2 kg	~ 93% 1RM	3 × 3 back squat, 3 × 3 front squat (100% 3RM), 3 × 6 knee extensions (100% of 6RM)	3 h/7 h/11 h	↓ Isokinetic leg extension peak torque at 60°-s^{-1} and total work^{a}, ↔ isokinetic leg extension peak torque at 240°-s^{-1} and total work^{a}, ↔ isokinetic leg extension peak torque at 240°-s^{-1} and total work at 3 h^{b}, ↓ non-CMJ height at 3–11 h^{a}, ↔ electrical-induced stimulation force^{a}
		~ 65% 1RM	3 × 3 back squats, 3 × 3 front squat (70% 3RM), 3 × 6 knee extensions @ 76%6RM	3 h/7 h/11 h	↔ isokinetic leg extension peak torque at 60°-s^{-1} and 240°-s^{-1} or in total work^{b}, ↔ non-CMJ height at 3–11 h^{b}, ↔ electrical-induced-stimulation force^{a}
Russell et al. [15]	15 males; French top-tier rugby players Age: 24 ± 3 years Height: 186 ± 8 cm Mass: 98.2 ± 8.3 kg	75% 1RM	5 × 10 bench press (75% 1RM)	5 h	↓ 2.3% sprint 1 times^{c}, ↓ 2% sprint 2 times^{c}, ↔ sprints 3–6 times^{c}, ↔ CMJ height^{c}, ↔ reaction time^{c}, ↑ 17% salivary T^{c}, ↔ salivary C^{c}, ↓ salivary C^{b}
Saez de Villareal et al. [33]	12 males; volley ballers with > 2 years RT exp Age: 22.8 ± 2.65 years Height: 183.7 ± 4.1 cm Mass: 76.9 ± 8.0 kg	80–85% 1RM	2 × 4 concentric back squats starting from 85% knee flexion (80% 1RM), 2 × 2 concentric back squats starting from 85% knee flexion (85% 1RM)	6 h	↔ CMJ height^{b}, ↑ 3% DJ height from optimal box height to maximise power output^{b}, ↔ loaded CMJ height using optimal load to maximise power output^{b}
		80–95% 1RM	2 × 4 concentric back squats starting from 85% knee flexion (80% 1RM), 2 × 2 concentric back squats starting from 85% knee flexion (90% 1RM), 2 × 1 back squats (95% 1RM)	6 h	↔ CMJ height^{b}, ↑ 5.5% DJ height from optimal box height to maximise power output^{b}, ↔ loaded CMJ height using optimal load to maximise power output^{b}
		30% 1RM	3 × 5 concentric back squats starting from 85% knee flexion (30% 1RM)	6 h	↔ CMJ height^{b}, ↔ DJ height from optimal box height to maximise power output^{b}, ↔ loaded CMJ height using optimal load to maximise power output^{b}

Table 2 (continued)

Study	Participants	Intensity	Stimulus	Recovery	Key outcomes
Sparkes et al. [27]	14 males; semi-professional football players Age: 22.1 ± 2.1 years Height: 180.0 ± 8.0 cm Mass: 79.3 ± 12.2 kg	85% 1RM	4 × 4 parallel back squats, Romanian deadlift and barbell hip thrust (85% 1RM)	2 h	↓ salivary T^b, ↓ salivary C^b, ↑ T/C ratio[b]
Woolstenhulme et al. [36]	18 females; Division 1 college basketball players Age: 18–22 years Height: 180 ± 32 cm Mass: 74 ± 9 kg	~67–87% 1RM	3 × 5 hang cleans, 3 × 5 push jerks (100% 5RM), 4 × 8–12 bench press, 4 × 8–12 back squat, 4 × 8–12 overhead press (100% 8–12RM), 3 × 12 prone leg curl (100% 12RM), 3 × 8–12 DB incline press (100% 8-12RM)	6 h	↔ Free throw shooting accuracy[c], ↔ speed shot shooting[c], ↔ vertical jump performance[c], ↔ anaerobic power output[c]

Data presented as % change with significance level set at $p < 0.05$

↑ significant increase, ↓ significant decrease, ↔ no significant difference, *a* when compared to a within study comparative intervention, *b* when compared to pre-trial comparative measures, *c* when compared to control comparative trial, *RT* resistance training, *CMJ* counter-movement jump, *DJ* drop jump, *BOST* backwards overhead shot throw, V_1*-load* load that elicits a velocity of 1.0 $m.s^{-1}$, *RFD* rate of force development, VO_2 volume of oxygen uptake, *RER* respiratory exchange rate, *RPE* rate of perceived exertion, *RM* repetition max, *C* cortisol, *T* testosterone, *GH* growth hormone

differences were observed in reaction time or repeat sprint ability at 5 h post cycle sprints [15] or in isometric leg extensor strength 1 h or 3 h post cycle sprints [40] when compared to controlled trials. Finally, there were no changes in the running speed or VO_2 max of moderately trained triathletes during an incremental running test performed 5 h after an incremental cycle test to failure [43].

No studies showed increases in either serum or salivary testosterone following cycling interventions [15, 39, 42] and in one case serum testosterone decreased 1 h post cycle sprints when compared to a controlled trial [40]. Increases in salivary cortisol concentrations were reported 1 h after cycle sprints [39] and serum cortisol increased 1 h after both cycle sprints and endurance cycling; however, levels returned to baseline 4 h after the endurance cycling intervention [40, 42]. Similarly, growth hormone increased 1 h post endurance and sprint cycling, before returning to baseline at 3 and 4 h, respectively [40, 42]. Blood lactate was increased 1 h post sprints in recreationally trained males, but had returned to baseline after 3 h of recovery [40], with no differences in blood lactate observed 5 h post endurance cycling in moderately trained triathletes [43].

3.3 Running Interventions

Running-based exercise interventions were used in six studies (see Table 4). Many of the studies compared multiple variants of a running-based intervention protocol. Three studies implemented maximal intensity sprints; two used straight-line sprints [14, 23], whereas one implemented shuttle sprints (i.e. 20 m out, 180-degree turn, back 20 m) [15]. Two studies used a single bout of endurance exercise, one used a 90 min cross-country run at ~ 70% of VO_2 max [30], and the other implemented a 6-mile run at maximal capacity [45]. A single study applied three different high-intensity interval training (HIIT) sessions of matched workloads and varying interval durations [46].

Improvements in sprint performance were observed 5–6 h post maximal sprints in semi-professional and professional rugby players [14, 15]. A 3.9% ($p < 0.001$) improvement in CMJ height was observed 5 h after shuttle sprints [15] but showed no change 2 or 6 h after straight-line sprints [14, 23]. Cardiorespiratory responses to HIIT conditions were similar in moderately trained males; however, 30 s work and rest intervals caused the least autonomic disruption when compared to intervals of shorter and longer duration (i.e. 15:15, 60:60) [46]. A decrease in salivary testosterone and cortisol was observed 2–6 h after maximal intensity sprints [14, 15, 23] when compared with pre-trial measures; however, testosterone concentrations were higher than controlled trials [14, 15]. The cortisol responses were inconsistent between studies, with an increase in salivary cortisol observed 6 h [14], but not 5 h [15] post maximal sprints, when compared to

Table 3 Summary of findings from studies using cycling interventions ($n=7$)

Study	Participants	Type	Stimulus	Recovery	Key outcomes
Beaven et al. [39]	7 males; recreationally trained Age: 27 ± 7 years Height: 174.1 ± 4.9 cm Mass: 83.5 ± 20.1 kg	Repeated maximal sprint	2 × 30 s. maximal effort cycle sprint (10% BW load), 60 s. rest between repetitions	1–8 h	Moderate 79% increase in C at 1 h post^{a}. Unclear or trivial results in measures of T and C at all other timepoints^{a}
Bentley et al. [43]	8 (6 M; 2 F); moderately trained triathletes Age: 26.2 ± 3.4 years Mass: 67.3 ± 9.1 kg	Single endurance	1 × incremental cycle test; 100 W for 10 min. followed by 30 W increments for 3 min. intervals until failure	5 h	↔ Lactate threshold^{a}, ↔ VO$_2$ max^{a} ↔ running speed^{a}
Goto et al. [40]	9 males; RT and sprint training exp Age: 23.8 ± 0.8 years Height: 172.6 ± 2.1 cm Mass: 69.5 ± 2.4 kg	Repeated maximal sprint	8 × 5 s. maximal effort cycle sprints (5% BW load), 30 s. rest between repetitions	1 h	↔ Mean pedal rate, power output, CMJ height, isometric knee extension torque^{b}, ↑ 77% lactate^{b,c}, ↔ epinephrine and norepinephrine^{a,b}, ↑ growth hormone^{b,c}, ↓ serum free T^{c}, ↑ 39% serum C^{b}
		Repeated maximal sprint	8 × 5 s. maximal effort cycle sprints (5% BW load), 30 s. rest between repetitions	3 h	↔ Mean pedal rate, power output CMJ height, isometric knee extension torque^{b}, ↔ lactate concentrations^{c}, ↔ epinephrine and norepinephrine^{a,b}, ↔ growth hormone^{c}
Ronsen et al. [41]	9; elite endurance athletes; triathletes (4), speed skaters (5) Age: 23 ± 1.8 years Height: 182 ± 8.6 cm Mass: 75 ± 5.4 kg	Single endurance	1 × 65 min cycle (70% VO$_2$ max)	1–6 h	↑ oxygen uptake^{c}, ↓ 11.4% RER in the 1–5 h post exercise^{c}
		Repeated endurance	2 × 65 min cycle (70% VO$_2$ max) 3 h rest between repetitions	1–6 h	↓ RER during second exercise session^{b,c}, ↓ 18.9% RER in the 1–5 h post exercise^{c}
		Repeated endurance	2 × 65 min cycle (70% VO$_2$ max), 6 h rest between repetitions	1–6 h	↑ oxygen uptake^{c}, ↓ 17.3% RER in the 1–5 h post exercise^{c}
Ronsen et al. [42]	9; elite endurance athletes Age: 21–27 years Mass: 74.7 ± 5.4 kg	Single endurance	1 × 65 min cycle (75% maximal VO$_2$ uptake)	1–4 h	↔ epinephrine and norepinephrine at any timepoints^{a}, increase in C at 1 h post^{a,d}, no difference in C 4h post^{a,d}, increase GH at 1 h post^{a,d}, no difference in GH 4 h^{a,d}, decrease in insulin at 1 h post^{a,d}, increase in insulin 2 h post^{a,d}, no difference in T post exercise^{a,d}
		Repeated endurance	2 × 65 min cycle (75% maximal VO$_2$ uptake), 3 h rest between repetitions	1–4 h	↔ epinephrine and norepinephrine at any timepoints^{a}, increase in C at 1 h post^{a,d}, no difference in C 4 h post^{a,d}, increase GH at 1 h post^{a,d}, no difference in GH 4 h^{a,d}, decrease in insulin at 1 h post^{a,d}, increase in insulin 2 h post^{a,d}, no difference in T post exercise^{a,d}
Russell et al. [15]	15 males; French top-tier rugby players Age: 24 ± 3 years Height: 186 ± 8 cm Mass: 98.2 ± 8.3 kg	Repeated maximal sprint	6 × 6 s. maximal effort cycle sprints (7.5% BW load), 54 s. rest between repetitions	5 h	↔ repeat sprints^{c}, ↑ 2.3% CMJ height^{c}, ↔ reaction time^{c}, ↔ salivary T^{c}, ↔ salivary C^{c}, ↓ salivary C^{a}

Table 3 (continued)

Study	Participants	Type	Stimulus	Recovery	Key outcomes
Stokes et al. [44]	8 males; recreationally trained Age: 23 ± 2.0 years Height: 180.2 ± 6.9 cm Mass: 82.7 ± 11.5 kg	Repeat maximal sprint	1 × 30 s. maximal effort cycle sprint (7.5% BW load)	1 h	↔ any sprint performance variables^{d,e}, increase in serum GH^{d,e}, decrease 8.6% in IGFBP-1^{d,e}, decrease 4.0% IGF-1 binary complex^{d,e}, increase 4% in IGFBP-1 saturation percentage^{d,e}
		Repeat maximal sprint	1 × 30 s. maximal effort cycle sprint (7.5% BW load)	4 h	↔ any sprint performance variables^{d,e}, increase in serum GH^{d,e}, increase 9.7% in IGFBP-1^{d,e}, no change in IGF-1 binary complex^{d,e}, decrease 21% in IGFBP-1 saturation percentage^{d,e}

Data presented as % change with significance level set at $p < 0.05$

↑ significant increase, ↓ significant decrease, ↔ no significant difference, *a* when compared to pre-trial comparative measures, *b* when compared to a within study comparative intervention, *c* when compared to control comparative trial, *d* significance not reported, *e* compared to initial exercise intervention, *CMJ* counter-movement jump, *BW* body weight, *W* watts, VO_2 volume of oxygen uptake, *RER* respiratory exchange rate, *C* cortisol, *T* testosterone, *GH* growth hormone, *IGF* insulin-like growth factor, *IGFBP-1* insulin-like growth factor binding protein 1

controlled trials. In comparison, no changes in testosterone, cortisol, glucose, glucagon or insulin were observed following endurance interventions; however, chromium excretion increased by 380% ($p < 0.05$) in male runners following a 6-mile run at maximal capacity when compared to pre-trial measures [30, 45].

3.4 Other Exercise Interventions

Six studies implemented exercise interventions that did not fit exclusively within the categories of RT, running and cycling (see Table 5). Two studies implemented combined RT and cycling interventions [27, 34], whereas single studies implemented boxing intervals [39], small-sided games [27] and DJ [47]. One study assessed loaded and unloaded jumping and a volleyball-specific exercise routine [33].

Loaded CMJ and DJ height increased by 9.0% ($p < 0.05$) and 4.2% ($p < 0.05$), respectively, with no changes in unloaded CMJ height, when assessed 6 h after a loaded CMJ intervention [33]. No differences were observed in loaded CMJ, unloaded CMJ or DJ height after a volleyball-specific warm-up or a DJ intervention performed 6 h earlier [33]. A decrease in testosterone and cortisol, but an increase in the testosterone to cortisol ratio (T/C ratio), was reported 2 h after football-specific small sided games [27]. No changes were observed in mTOR signalling pathways 1–3 h after a combined RT and cycling intervention [27, 34], or in the testosterone or cortisol concentrations of recreationally trained males 1–8 h after high-intensity boxing rounds [39].

3.5 Risk of Bias Analysis

All studies received a score of 4, 5 or 6 out of 10 on the PEDro scale as outlined in Table 6. Studies receiving a score of 9–10 are considered to be of ‘excellent’ methodological quality, a score of 6–8 is considered to be of ‘good’ quality, a score of 4–5 is considered to be ‘fair’ and a score below 4 indicates ‘poor’ methodological quality [48]. The ‘fair’ and ‘good’ scores observed were attributed to the applied nature of the included studies, which made it difficult for group allocation to be concealed and limited the ability to blind participants and researchers to study interventions.

4 Discussion

The aim of this review was to assess the use of acute exercise interventions to improve physical performance and athlete readiness in team-sport athletes. An extensive range of exercise modalities and individual strategies were assessed as part of this review, with many easily applied on the day of competition. The results show that different exercise modalities, volumes and intensities, combined with varying

Table 4 Summary of findings from studies using running interventions ($n = 6$)

Study	Participants	Type	Stimulus	Recovery	Key outcomes
Anderson et al. [45]	9 males; runners Age: 31.9 ± 7.8 years Height: 177.2 ± 8.1 cm Mass: 75.2 ± 13.4 kg	Single endurance	1 × 6-mile run at (or near) maximal capacity	2 h	↑ 380% chromium excretion^{a}, ↔ glucose^{a}, ↔ glucagon^{a}, ↔ insulin^{a}
Cipryan et al. [46]	12 males; moderately trained Age: 22.8 ± 1.7 years Height: 183.9 ± 7.8 cm Mass: 77.0 ± 8.4 kg	Repeated maximal sprint	48 × 15:15 s. intervals (100%:60% VO_2 max.)	1 h	Almost certain large decrease in RR^{a}, unclear change in ln rMSSD/RR^{a}, very likely moderate decrease in ln rMSSD^{a}
				3 h	Possibly small increase in RR^{a}, possibly trivial decrease in ln rMSSD/RR^{a}, unclear change in ln rMSSD^{a}, likely small increase in TCP^{a}
		Repeated maximal sprint	24 × 30:30 s intervals (100%:60% VO_2 max.)	1 h	Very likely moderate decrease in RR^{a}, likely moderate increase in ln rMSSD/RR^{a}, possibly small decrease in ln rMSSD^{a}
				3 h	Unclear change in RR^{a}, possibly small increase in ln rMSSD/RR^{a} and ln rMSSD^{a}, likely small increase in TCP^{a}
		Repeated maximal sprint	12 × 60:60 s. intervals (100%:60% VO_2 max.)	1 h	Almost certain moderate decrease in RR^{a}, likely small increase in ln rMSSD/RR^{a}, likely moderate decrease in ln rMSSD^{a},
				3 h	Unclear change in RR^{a}, possibly small increase in ln rMSSD/RR^{a} and ln rMSSD^{a}, almost certain moderate increase in TCP^{a}
Cook et al. [14]	18 males; semi-professional rugby players Age: 22 ± 1 years Height: 184 ± 5 cm Mass: 93.7 ± 8.3 kg	Repeated maximal sprint	5 × 40 m maximal effort sprints, 1 min. active recovery between repetitions	6 h	↓ 0.8% 40 m sprint time^{b}, ↔ 3RM bench press^{b}, ↔ 3RM squat^{b}, ↔ CMJ peak power output^{b}, ↓ salivary T^{a}, ↑ salivary T^{b}, ↓ salivary C^{a}, ↑ salivary C^{b}
Jensen et al. [30]	7 males; well trained Age: 25 ± 2.5 years Height: 179.9 ± 4.0 cm Mass: 74.7 ± 7.0 kg	Single endurance	1 × 90 min cross-country run at ~ 70% VO_2 max	2 h/4 h/6 h	↔ T concentrations at any timepoint^{a,b}
Johnston et al. [23]	7 males; academy rugby players Age: 25 ± 2.5 years Height: 179.9 ± 4.0 cm Mass: 74.7 ± 7.0 kg	Repeated maximal sprint	6 × 50 m maximal effort sprints, 5 min. rest between repetitions	2 h	↔ CMJ height^{a}, ↔ CMJ peak power^{a}, ↔ T^{a}, ↓ 39.5% C^{a}, ↑ 21.4% creatine kinase^{a}, ↔ lactate^{a}, ↑ 83.8% muscle soreness^{a}
Russell et al. [15]	15 males; French top-tier rugby players Age: 24 ± 3.0 years Height: 186 ± 8.0 cm Mass: 98.2 ± 8.3 kg	Repeated maximal sprint	6 × 40 m maximal effort sprints (20 m, 180° turn, 20 m), 20 s. rest between repetitions	5 h	↓ 2.2% sprint 1 time^{b}, ↓ 2.4% sprint 2 time^{b}, ↔ sprints 3–6 times^{b}, ↑ 3.9% CMJ height^{b}, ↔ reaction time^{b}, ↑ 22% salivary T^{b}, ↔ salivary C^{b}, ↓ salivary C^{a}

↑ significant increase, ↓ significant decrease, ↔ no significant difference, *a* when compared to pre-trial comparative measures, *b* when compared to control comparative trial, *CMJ* counter-movement jump, *ln rMSSD* square root of the mean sum of the squared differences between RR intervals, *RR* intervals between successive heart beats, *TCP* total circulating protein, *VO_2* volume of oxygen uptake, *RER* respiratory exchange rate, *RPE* rate of perceived exertion, *RM* repetition max, *C* cortisol, *T* testosterone. Data presented as % change with significance level set at $p < 0.05$

recovery intervals, lead to various physiological and performance outcomes. The benefits of these outcomes in relation to performance and athlete readiness on the day of competition will be evaluated in the following discussion.

4.1 Resistance Training

Resistance training was the most commonly used exercise intervention in the studies reviewed and has been widely implemented in recent priming research [5]. Cook et al. [14] demonstrated upper- and lower-body RT using heavy loads significantly improved all markers of performance and increased testosterone and cortisol concentrations when compared to a controlled trial [14]. In contrast, Russell et al. [15], whilst observing similar increases in testosterone 5 h post moderate-intensity upper-body RT, showed no change in CMJ height or cortisol concentrations. A comparison of these studies shows both used highly trained rugby players (i.e. semi-professional, professional) with similar sample sizes of 18 and 15, respectively [14, 15]. However, Cook et al. [14] implemented loads of up to 100% 3RM for back squat and bench press at low volumes, whereas Russell et al. [15] used high-volume bench press, with participants completing 5 sets of 10 repetitions at 75% 1RM. This difference between the studies suggests that loading characteristics likely play a key part in the effectiveness of a RT intervention; however, this was not evident in all studies [36]. The concept of applying sufficient load is supported by Mason et al. [37] who observed increases in upper-body but not lower-body power output, 1 h and 45 min post RT in 13 academy rugby players. The authors reported a large negative relationship between initial force measures and changes in force output in the bench press exercise and a very large positive relationship between band tension at the top position of the back squat and increases in peak power output [37]. These findings are aligned with previous research [14] and suggest that increased relative load may result in increased performance outcomes hours later.

Whilst an increase in physiological load is suggested to improve the priming response following RT [37], it is important to consider exercise intensity against total volume, fatigue response and recovery rates following RT. When assessing different RT volumes and intensities, Gonzalez Badillo et al. [28] observed a significant increase in back squat V_1-load (8.2%; $p=0.003$) and CMJ height (7.8%; $p=0.001$), yet an unclear improvement in bench press 6 h after moderate-intensity RT versus high-intensity RT [28]. These findings support the work of Raastad and Hallen [25] who reported an initial decrease in peak knee torque following both moderate- and high-intensity RT, but observed a return to baseline at 3 h, and 11 h post RT, respectively [25, 28].

Similar patterns of recovery were also observed by Linnamo et al. [31], who showed an initial reduction in peak force and maximal RFD in bilateral leg extensions following maximal (i.e. 5 × 10 leg extensions and bench press performed at 10RM), and explosive (i.e. 5 × 10 leg extensions and bench press performed at 40% of 10RM with maximal movement velocity) strength conditions. However, only the explosive strength condition had returned to baseline 2 h later, whilst leg extension peak force and RFD were still reduced 12 h post the maximal strength condition [31]. Across these studies, the results indicate that high RT loading may lead to a greater acute fatigue than moderate-intensity interventions. However, when comparing these findings to studies that reported improvements in performance after higher individual RT loads [14, 37], the overall training volumes in the interventions reporting a decrease in performance were greater. This suggests that low rather than high-volume RT may be more beneficial as a game day priming strategy, as high volumes can lead to increased fatigue and a reduction in neuromuscular function [49], which may offset any positive priming effects associated with prior RT. It is important to note that these studies were conducted with untrained [31] or recreationally trained participants [28], and those competing in strength and power sports (i.e. powerlifting, javelin, speed skating) [25]. Therefore, it is unknown if similar findings would be observed in team-sport athletes under the same conditions.

Another consideration when using RT as a game day priming strategy is the role of movement specificity. Ekstrand et al. [13] observed improvements in BOST performance 4–6 h after morning RT in 14 trained throwers. Interestingly, no differences were observed in CMJ peak power following the RT or controlled trials. The authors' suggestion of potential kinematic differences between the BOST and CMJ, with the arm movement patterns of the BOST more closely aligned to power cleans, may provide some insight into the different performance outcomes observed [13]. This suggestion is supported by previous research into BOST performance which reported a strong association ($r=0.90$) between the BOST and clean and jerk loads [50], yet only a moderate relationship ($r=0.59$) between the BOST and CMJ peak power [51]. The notion of movement specificity is supported by increases in throwing, jumping and sprinting performance when the priming activity implemented a similar movement pattern [14, 15, 33, 37]. This suggests that the use of specific movements may have a greater transfer to subsequent performance than a generic exercise intervention. However, more research is needed to establish a priming strategy to specifically address the wide range of physical performance capabilities required to succeed in team sports.

Changes in performance outcomes in the 1–12 h following RT have been widely reported. However, studies have

Table 5 Summary of findings from studies using other exercise interventions (n = 6)

Study	Participants	Exercise	Stimulus	Recovery	Key outcomes
Apro et al. [27]	10 males; moderately trained Age: 26 ± 2 years Height: 179 ± 2 cm Mass: 85 ± 3 kg	Combined RT and cycling	4 × 8–10 leg press (85%1RM), 4 × 10–12 leg press (75%1RM), 2 × sets to fatigue leg press (65%1RM); 15 min rest; 30 min. cycle at 70% of VO_2 max	1 h/3 h	↔ signalling of mTOR pathways^{a}, ↔ plasma glucose at 1 h^{b}, ↔ plasma glucose at 3 h^{a}, ↑ 311% lactate at 1 h^{b}, ↔ lactate at 3 h^{a}
Apro et al. [34]	8 males; > 6 months RT exp Age: 26 ± 2 years Height: 183 ± 2 cm Mass: 85 ± 2 kg	Combined RT and cycling	5 × 4 min cycle intervals at 85% VO_2 max., immediately followed by 4 × 8–10 leg press (80% 1RM), 4 × 10–12 leg press (70% 1RM), 2 × sets to fatigue leg press (60% 1RM)	1.5 h/3 h	Prior AMPK activation through endurance exercise does not inhibit mTOR1 signalling 1.5 or 3 h post RT exercise^{a}
Beaven et al. [39]	7 males; recreationally trained Age: 27 ± 7 years Height: 174.1 ± 4.9 cm Mass: 83.5 ± 20.1 kg	Boxing	2 × 30 s maximal effort boxing rounds, 60-s rest between rounds	1–8 h	Unclear or trivial results in measures of T and C at all timepoints from 1–8 h^{b}
Dargeviciute et al. [47]	9 males; healthy, untrained Age: 26.0 ± 9.0 years Height: 184.8 ± 4.4 cm Mass: 85.2 ± 9.5 kg	DJ	50 × DJ from 40 cm box, 30 s. rest between repetitions	1 h	↓ isometric leg extension torques electrically evoked at 20 Hz and 50 Hz^{b}, positive correlation between mechanical work and RFD ($R^2 = 0.76$; $p < 0.001$)
Saez de Villareal et al. [33]	12 males; volleyball players with > 2 years RT exp Age: 22.8 ± 2.65 years Height: 183.7 ± 4.1 cm Mass: 76.9 ± 8.0 kg	Loaded CMJ	3 × 5 loaded CMJ	6 h	↔ CMJ height^{b}, ↑ 4.2% DJ height from optimal box height to maximise power output^{b}, ↑ 9.0% loaded CMJ height using optimal load to maximise power output^{b}
		DJ	3 × 5 DJ from pre-determined optimal height	6 h	↔ CMJ height^{b}, ↔ DJ height from optimal box height to maximise power output^{b}, ↔ loaded CMJ height using optimal load to maximise power output^{b}
		Volleyball-specific warm-up	5 min. submaximal running at 9 km.h; 2 min. multi-directional run (i.e. forwards, backwards, sideways); 5 × two-foot ankle hops; 5 × 5 × split squat jumps; 5 × standing jump and reach; 10 × rim jump; 5 min. light stretching	6 h	↔ CMJ height^{b}, ↔ DJ height from optimal box height to maximise power output^{b}, ↔ loaded CMJ height using optimal load to maximise power output^{b}
Sparkes et al. [27]	14 males; semi-professional football players Age: 22.1 ± 2.1 years Height: 180.0 ± 8.0 cm Mass: 79.3 ± 12.2 kg	Small sided games	6 × 7 min blocks with 2 min rest between blocks; 5 v 5 on a pitch on 24 m × 29 m; aim to win each 7 min block by scoring more goals than the opposition	2 h	↓ salivary T^{b}, ↓ salivary C^{b}, ↑ T/C ratio^{b}

Data presented as % change with significance level set at $p < 0.05$

↑ significant increase, ↓ significant decrease, ↔ no significant difference, *a* when compared to a within study comparative intervention, *b* when compared to pre-trial comparative measures, *RT* resistance training, *CMJ* counter-movement jump, *DJ* drop jump, *RFD* rate of force development, *VO_2* volume of oxygen uptake, *BW* body weight, *RM* repetition max, *AMPK* AMP-activated protein kinase, *C* cortisol, *T* testosterone, *GH* growth hormone

Table 6 PEDro scale for the quality assessment of the articles which satisfied the inclusion criteria [21]

Study	PEDro scale criterion measure											Total/10
	1	2	3	4	5	6	7	8	9	10	11	
Anderson et al. [45]	+	–	–	+	–	–	–	+	+	+	+	5/10
Apro et al. [27]	+	+	–	+	–	–	–	+	+	+	+	6/10
Apro et al. [34]	+	+	–	+	–	–	–	+	+	+	+	6/10
Beaven et al. [39]	+	+	–	+	–	–	–	+	+	+	+	6/10
Bentley et al. [43]	+	+	–	–	–	–	–	+	+	+	+	5/10
Bird et al. [16]	+	+	+	+	–	–	–	–	+	+	+	6/10
Cipryan et al. [46]	+	+	–	+	–	–	–	+	+	+	+	6/10
Cook et al. [14]	+	+	–	–	–	–	–	+	+	+	+	5/10
Dargevictiute et al. [47]	+	–	–	+	–	–	–	+	+	+	+	5/10
Ekstrand et al. [13]	+	–	–	–	–	–	–	+	+	+	+	4/10
Goto et al. [40]	+	+	–	–	–	–	–	+	+	+	+	5/10
Gonzalez-Badillo et al. [28]	+	–	–	+	–	–	–	+	+	+	+	5/10
Hakkinen et al. [35]	+	–	–	+	–	–	–	+	+	+	+	5/10
Hakkinen et al. [29]	+	–	–	+	–	–	–	+	+	+	+	5/10
Jensen et al. [30]	+	–	–	–	–	–	–	+	+	+	+	4/10
Johnston et al. [23]	+	+	–	+	–	–	–	+	+	+	+	6/10
Kraemer et al. [24]	+	+	–	+	–	–	–	+	+	+	+	6/10
Kraemer et al. [17]	+	+	–	+	–	–	–	+	+	+	+	6/10
Linnamo et al. [31]	+	–	–	–	–	–	–	+	+	+	+	4/10
Mason et al. [37]	+	+	–	+	–	–	–	+	+	+	+	6/10
Palmer & Sleivert [32]	+	+	–	+	–	–	–	+	+	+	+	6/10
Raastad & Hallen [25]	+	–	–	+	–	–	–	+	+	+	+	5/10
Ronsen et al. [42]	+	+	–	–	–	–	–	+	+	+	+	5/10
Ronsen et al. [41]	+	+	–	+	–	–	–	+	+	+	+	5/10
Russell et al. [15]	+	+	–	+	–	–	–	+	+	+	+	6/10
Saez Saez de Villareal et al. [33]	+	+	–	+	–	–	–	+	+	+	+	6/10
Sparkes et al. [27]	+	–	–	+	–	–	–	+	+	+	+	6/10
Stokes et al. [44]	+	+	–	+	–	–	–	+	+	+	+	6/10
Woolstenhulme et al. [36]	+	–	–	+	–	–	–	+	+	+	+	5/10

Each satisfied criterion measure, excluding item 1, contributes 1 point to the total PEDro score (range 1–10 points). + indicates criterion was clearly satisfied; – indicates the criterion was not clearly satisfied; Criterion measures were as follows: 1. Eligibility criteria were specified; 2. Participants were randomly allocated to groups; 3. Allocation was concealed; 4. The groups were similar at baseline regarding the most important prognostic indicators; 5. There was blinding of participants; 6. There was blinding of therapists who administered the therapy; 7. There was blinding of all assessors who measured at least one key outcome; 8. Measures of at least one key outcome were obtained from more than 85% of the participants initially allocated to groups; 9. All participants for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome were analysed by intention to treat; 10. The results of between-group statistical comparisons were reported for at least one key outcome; 11. The study provided both point measures and measures of variability for at least one key outcome

also assessed physiological responses to exercises and how these responses may be related to physical performance and athlete readiness. Several studies investigated testosterone and cortisol responses to exercise both independently and in association with performance outcomes. No studies reported changes in serum or salivary testosterone or cortisol when compared to controlled trials, except for Hakkinen et al. [29] who observed an increase in serum cortisol 1–2 h post RT; Cook et al. [14] who observed an increase in salivary testosterone and cortisol 6 h after; and Russell et al. [15] who observed an increase in salivary testosterone 5 h after RT. Differences in testosterone and cortisol responses from pre to post intervention were observed; however, it is unclear if this is influenced by RT, attributed to changes in circadian patterns or is in response to changes in athlete readiness [14, 16, 17].

4.2 Cycling

The use of cycling as a priming strategy may be of interest to team sports due to the ability to reduce impact through the lower body on the day of competition. This could be an appealing option to coaches and athletes concerned with the fatiguing effects of RT or running-based interventions implemented prior to a match. However, consideration must also be given to the lack of specificity (i.e. muscle contraction [52], metabolic response [53] when applying cycling as a priming method to improve subsequent team-sport performance. Goto et al. [40] reported no changes in isokinetic leg strength or CMJ height 1 or 3 h post cycle sprints whereas Russell et al. [15] reported a 2.3% increase in CMJ height 5 h post cycle sprints of similar volume and intensities. In comparing these studies, an extended recovery period and an increase in load during each repetition may have contributed to the differences observed in CMJ performance. Interestingly, Russell et al. [15] assessed 15 semi-professional Rugby players with a mean mass of 98.2 kg, compared to the 9 recreationally trained participants with a mean mass of 69.5 kg used in the study by Goto et al. [40]. Considering the mean mass and applying the loading strategies used in each study, a 47% higher average workload was implemented by Russell et al. [15] which may have contributed to the increases in CMJ height that were observed. Russell et al. [15] also reported no change in repeat sprint ability compared to a controlled trial, whereas Bentley et al. [43] saw no difference in running speed, lactate threshold or VO_2 max of 8 triathletes during a 5-km time trial when preceded by a cycling intervention or rest. These findings suggest that 5 h may be a long enough duration to recover from cycling exercise to perform short duration repeated sprints or steady-state endurance exercise. However, there is currently insufficient evidence to suggest cycling will improve physical performance for team-sport athletes based on these studies alone.

An endurance bout of exercise led to a reduction in respiratory exchange ratio of 11.4–18.9% below that of a controlled trial in the 1–5 h following exercise [41]. A lower respiratory exchange ratio signals a transition from carbohydrates to lipid as a fuel source and is suggested to be beneficial for endurance performance by delaying time to fatigue during low-moderate exercise [54]. A delay in fatigue during low-moderate exercise also indicates an increase in oxidative metabolism, which influences early phosphocreatine resynthesis following exercise [55]. Therefore, low–moderate exercise may provide some positive priming effects; however, further research is needed to determine if an increase in phosphocreatine resynthesis leads to changes in performance or readiness in the 1–12 h following exercise. In addition to post exercise phosphocreatine resynthesis, another consideration with relevance to team-sport athletes and game day priming is the time course response of blood lactate concentrations following exercise. Goto et al. [40] assessed blood lactate responses to maximal cycle sprints 1 and 3 h prior to RT. The authors reported no differences in lactate responses to RT, despite the 1 h recovery condition commencing RT with higher baseline lactate levels [40]. These findings suggest that a higher lactate concentration following maximal effort cycle sprints may not influence the lactate response to a secondary bout of exercise when conducted in the subsequent 1–3 h.

Only two studies compared cycling to other modes of exercise. Beaven et al. [39] observed a moderate increase in salivary cortisol in 7 recreationally trained males 1 h after cycle sprints, but not boxing intervals or in response to a video game, with no changes in testosterone observed 1–8 h post exercise [39]. Russell et al. [15] observed no change in testosterone or cortisol concentrations following cycle sprints compared to a controlled trial, yet observed a 22% ($p < 0.001$) increase in testosterone following a running intervention comprising repeat sprints. The findings from these studies suggested that an increase in physiological stress, as opposed to psychological stress, may lead to greater hormonal responses in the hours following the stimulus. This suggestion is supported by Crewther et al. [56] who found an increase in testosterone following cycle sprints, but not after watching an aggressive video or a controlled trial. This study measured testosterone 15 min post trials, so it is unknown if the same response was evident across a 1–12 h period.

4.3 Running

Running-based priming interventions have a high practical application for team sports due to the ability to implement sessions with large groups of athletes, the familiarity of exercises and the limited resources required. A sprint protocol implemented by Cook et al. [14] led to improvements in 40 m sprint times but not in upper- or lower-body strength or CMJ peak power 6 h post intervention. Similarly, Russell et al. observed increases in CMJ height and repeat sprint ability. Whilst the total sprint volume was similar across studies (i.e. 5 × 40 m versus 6 × 40 m), Russell et al. included a 180° turn in their sprints (i.e. 20 m out, 180° turn, 20 m back) [15]. The addition of a turn to a straight-line run to make a shuttle can lead to an increase in physiological load [57]. The proposed increase in physiological load may help justify the small differences in performance outputs following the different sprint conditions implemented in these studies. An interesting finding from the work conducted by Russell et al. [15] was that although overall repeat sprint performance improved, the improvements in individual sprints were limited to the first 2 sprints of the 6-sprint protocol. This finding is possibly due to the effects of post-activation potentiation from the initial sprints acutely improving subsequent sprint performance [15].

When implementing shorter recovery periods, there were no reported changes in performance in 15 academy Rugby players; however, a sprint protocol led to an 83% increase in perceived muscle soreness 2 h later [23]. The increase in perceived muscle soreness was linked to an elevation in creatine kinase, an indirect biomarker of muscle damage [58]. These findings differed from other studies using sprint priming protocols as no changes in testosterone concentrations were observed after a 2 h recovery [23], yet there was an increase in testosterone when a longer recovery of 5–6 h was applied [14, 15]. It is important to note that although higher testosterone has been observed alongside improvements in performance, it is unknown if this relationship is causal [6, 14, 15]. A shorter recovery period of 1–3 h was also used to assess heart rate variability following HIIT using 15–60 s intervals [46]. Whilst all conditions had similar cardiorespiratory responses, HIIT using a 30:30 work to rest ratio had the lowest autonomic nervous system disruption and was the least strenuous based on rating of perceived exertion when compared to intervals of 15:15 and 60:60 [46]. These findings suggest that when using HIIT as a priming session, implementing 30:30 intervals may be more beneficial than 15:15 or 60:60 intervals when the recovery period is limited. However, further investigation is required to better understand the influence of HIIT as a priming intervention to improve performance and readiness.

4.4 Other

Whilst resistance training, cycling and running were the most frequently used interventions, the effects of other exercise modalities have been reported. Saez Saez de Villareal et al. [33] compared the effects of seven different exercise protocols on subsequent loaded CMJ, unloaded CMJ and DJ height. The load prescribed for the loaded CMJ was based on the optimal load to elicit maximal power output. This was individually determined using additional relative loads ranging from ‘bodyweight – 20 kg’, through to ‘bodyweight + 10 kg’ [33]. Improvements in loaded CMJ height were only observed following the loaded CMJ protocol, which supports the previously mentioned concept of specificity [14, 37]. Contrary to these findings, the DJ protocol did not lead to improvements in DJ height 6 h later; however, a 9% ($p < 0.05$) increase in DJ height was observed 6 h after the loaded CMJ protocol [33]. Whilst these findings support the concept of specificity, they highlight that matching movement patterns with appropriate loading strategies may be even more effective for eliciting a priming response [37].

With a focus on specificity, a strategy often used as a training tool in team-sport settings is small-sided games (SSGs), which allow coaches to adjust constraints to achieve desired physical, technical and tactical outcomes [27]. One study that assessed physiological responses to SSGs reported a decrease in testosterone and cortisol, and an increase in the T/C ratio after a 2 h recovery period [27]. Although this study did not assess performance outcomes 2 h after SSGs, the observed increase in the T/C ratio may be indicative of an increase in athlete readiness, although this is only speculative and suggested based on the previous research [7, 14]. Testosterone and cortisol concentrations were also assessed following high-intensity boxing rounds, with unclear or trivial responses observed in the 1–8 h following [39]. The authors suggested the lack of a physiological response may have been due to the recruitment of a smaller muscle mass when compared to other conditions such as cycling. In addition, as the participants in this study were not trained boxers, a lack of skill to consistently contact the focus pads made it difficult to achieve the desired intensity [39]. Whilst there is no conclusive evidence to support the use of SSG or boxing in priming strategies, consideration must be given to the different methodological approaches used in these studies, more specifically the lack of performance measures within 1–12 h of the intervention [27], and the skill level of the participants [39]. Before dismissing these strategies, further research assessing the use of SSG and boxing with the aim of priming for subsequent performance is needed.

5 Limitations and Future Research Recommendations

The aim of this review was to assess the use of acute exercise interventions to improve physical performance and athlete readiness in the subsequent 1–12 h; however, differences in methodological approaches in the included studies made it difficult to directly compare results. Individual studies used comparisons between pre and post trial measurements, comparisons between interventions and controlled trials and/or within study comparisons under different exercise conditions. The small sample sizes in the included studies may have been insufficient to account for the large inter- and intra-individual variation in hormone responses to exercise, with different sampling methods and protocols likely contributing to inconsistent findings between studies [59, 60]. Furthermore, only a limited number of studies were conducted with the explicit aim of assessing the effects of a priming intervention on subsequent performance or readiness in team-sport athletes. Instead most studies assessed responses to different exercise bouts across a 1–12 h period in a variety of populations. Therefore, the measures reported in this review may be presented outside of the context they were originally intended.

Future research in game day priming should consider the application of strategies on the day of competition.

Understandably, a greater evidence base is required before game day priming can be implemented with confidence; however, this research would provide a comparative analysis between the physiological and psychological effects observed in training or testing environments versus those observed under actual match day conditions. To account for the psychological influence of priming for team-sport performance, future research should be conducted alongside activities typical of the preparation for an actual match. This may include factors such as team interactions, travel, dietary intake and match day routines (i.e. warm-ups, team talks) typical to the day of competition.

Consideration should also be given to evaluating priming responses in specific populations, even within the broad categorisation of team-sports athletes, as responses may vary depending on the training status (i.e. training age, strength levels) and biological characteristics (age, sex) of an individual. Future research investigating the priming responses within different populations would add to the current literature and may provide further insight into the mechanisms and individual characteristics which contribute to the priming response. Finally, research to date is largely limited to performance outcomes in single tasks (i.e. CMJ), or short duration repeated tasks (i.e. repeat sprints). Future research investigating the effects of priming exercise on intermittent performance, skill execution and cognitive demands across extended periods would be beneficial, as this represents the conditions typically observed in team sports.

Finally, whilst changes in hormone concentrations have been reported in several studies, it is unclear if these changes were associated with changes in performance outcomes. Favourable testosterone and cortisol responses to exercise may contribute to improvements in athlete readiness prior to competition due to the reported link between these hormones and physical, psychological and behavioural change [7, 14, 15]; however, further investigation is needed.

6 Conclusion and Practical Applications

The findings from this review highlight that there are multiple exercise interventions which may be beneficial in improving physical performance and athlete readiness. The effectiveness of RT interventions appears to be influenced by exercise selection, intensity, volume and recovery intervals. From the studies reviewed, moderate- to high-intensity low-volume RT had the greatest effect on strength, power and speed performance. Therefore, team-sport athletes requiring the aforementioned qualities may benefit from RT interventions of 3 sets of 3–4 repetitions using heavy loads (i.e. > 80% 1RM), performed 4–6 h prior to competition. Consideration must be given to overall volume when implementing RT priming strategies as increased repetitions led to decreased performance and required extended recovery times, which can impact on the practicality of RT as a priming strategy on the day of competition. Furthermore, the use of compound movements (i.e. squats, power cleans) over isolated movements (i.e. leg extensions) appears to provide a greater priming response with less fatiguing effects and is recommended when implementing RT priming strategies. This response may be due to the physiological stress imparted on the overall system as opposed to specific musculature.

Although cycling may be an appealing option for athletes and coaches aiming to reduce load through the lower body in preparation for competition, this review supports the use of running-based strategies over cycling to improve subsequent performance in team-sport athletes. This recommendation is based on an increase in physiological responses and positive performance outcomes following running (high load) compared to cycling (low load). When determining the preferred running-based priming strategy for team-sport athletes, short duration (< 30 s), maximal intensity sprints are recommended. Sprint-based priming strategies have been shown to improve sprint times and repeat sprint ability 5–6 h later [14, 15], whereas no improvements were observed in performance or physiological markers at any timepoint following endurance exercise. The recommendation for running-based sprint protocols is further supported by the practicality of running-based interventions for team-sport athletes, the ability to implement sprint protocols with minimal resources, and the reduction in time required to implement sprint over endurance priming strategies.

The specificity of movement compared to the subsequent performance task has emerged as an important consideration when applying priming strategies on the day of competition, and has been supported in numerous studies [14, 15, 33, 37]. However, specific movements must be implemented alongside appropriate loading strategies to optimise the priming effect. From this review, it is evident that more research is needed to determine whether combinations of exercise modalities, intensities and recovery periods may lead to different performance and readiness responses for team-sport athletes on the day of competition.

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