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Deceleration and eccentric training for muscle damage protection and recovery in football: A narrative review with practical applications

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ABSTRACT: In modern football, the increase in match frequency, high-speed running, and intense accelerations and decelerations leads to a higher mechanical load to which players are exposed, thereby increasing their risk of tissue damage and injury. High-intensity decelerations occur more frequently than equivalent intensity accelerations and can impose substantially higher mechanical demands. These intense decelerations involve eccentric muscle contractions, which can lead to muscle damage, fatigue, and cumulative microtrauma in soft tissues. Since player availability remains a key to team success, training may need to consider enhancing athletes' ability to dissipate braking loads, build musculoskeletal strength, and ensure regular exposure to high-intensity decelerations. Due to their medium- and long-term effects, including neuromuscular adaptations and the 'repeated bout effect' (RBE), eccentric exercise plays a critical role in attenuating muscle damage from high-intensity decelerations. Furthermore, it has been proposed that players may potentially benefit from regular exposure to decelerations to improve their tolerance to the mechanical demands experienced during competition. However, despite their significance, adaptations from eccentric training through deceleration drills have not been thoroughly investigated, and there is limited research on the potential RBE from deceleration training in football. If eccentric and deceleration training are not properly prescribed, they can reduce physical readiness for future training, impair training quality and adaptation, and increase injury risk. In this article, we present a narrative review and provide practical, science-based considerations for sports science practitioners on eccentric and decelerative training, offering insights into recent developments in potential injury mitigation and physical development strategies for football.

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INTRODUCTION

Injuries represent one of the main concerns for both athletes and coaches, as they can have long-lasting health, psychological, and economic impacts on athletes and clubs [1, 2]. This scenario places medical and coaching staff under considerable pressure when a player is injured and throughout the entire return-to-play process, as they are expected to ensure the athlete's recovery and reintegration into competition as soon as possible [3, 4]. Within this context, strategies aimed at mitigating or reducing injury risk in football are of vital importance to maximize player availability [5, 6]. Although various strategies have been proposed to prevent injuries in football, resistance training (RT) has emerged as one of the most important components [7]. Eccentric training is widely used as an approach to help reduce injury risk [8, 9]. Eccentric contractions differ from other muscle contractions (i.e., isometric and concentric) in terms of mechanical, metabolic, and neural control [10]. Eccentric-only muscle contractions shift the force-length relationship toward longer muscle lengths, so that peak force is produced at a longer muscle length or more extended joint position, and can also shift the

force-velocity relationships in a direction consistent with greater maximal shortening velocity [10]. These adaptations are thought to be largely mediated by increases in fascicle length and the addition of sarcomeres in series, which may improve force production at longer lengths and reduce susceptibility to strain injury [11–13]. Furthermore, eccentric contractions are a primary cause of exercise-induced muscle damage (EIMD) within athletic populations [14]. Prolonged exposure to EIMD can reduce physical readiness for future training, thereby impairing both training quality and adaptive response [15]. However, eccentric contractions also induce short and long-term adaptations (i.e., neuromuscular, connective tissue, inflammatory) that protect against EIMD in subsequent sessions of eccentric exercise [16, 17]. This protective adaptation, known as the 'repeated bout effect' (RBE), is characterized by faster recovery of EIMD-related parameters compared to the initial exercise bout, with effects that can last up to several weeks [16–19]. Considering that RBE is specific to exercised muscle groups [20] and may have better transfer to sporting activities with multi-joint actions [16], exercises should aim to replicate sport-specific actions [14, 21].

With tactical evolutions and increasing number of matches, players are exposed to a greater frequency of high-speed running and sprinting actions, and a higher number of high-intensity accelerations and decelerations [22, 23]. It is also envisaged that these demands will continue to evolve in future years [24]. Among these external load variables, the accelerations and decelerations are major sport-specific actions that contribute substantially to the overall biomechanical load in football [25–31]. High-intensity decelerations have been reported to occur up to 2.9 times more often than high-intensity accelerations [26] and can impose mechanical demands up to 65% greater than any other match-related activities [25, 32]. Deceleration refers to the action performed during sporting scenarios that precedes a change of direction (COD) maneuver [33] or an action immediately performed following a sprint to reduce momentum [1, 34]. During deceleration, lower limb muscles can experience eccentric muscle contractions to resist and control joint flexion, absorb energy and slow down the body's center of mass [35]. Additionally, decelerations may increase the risk of EIMD because braking involves high-intensity eccentric contractions [36], during which key lower-limb muscles can generate peak forces of approximately 3–5 times body weight and lengthen at rates of about 0.4 to 1.6 times their resting length per second, thereby promoting repetitive mechanical stress and strain, fatigue, and cumulative tissue microtrauma [26, 37]. Considering that team schedules are increasingly characterized by congested fixture periods, with matches occurring every 3–4 days, football players may be exposed, if insufficiently prepared, to a cycle of progressive muscle fatigue and tissue damage, leading to chronic elevations in EIMD markers [36, 38]. Incorporating low-dose (microdose) eccentric exercise during congested competitive periods may confer a protective effect that attenuates competition-induced muscle damage and promotes faster recovery times [39].

Surprisingly, there are no experimental studies with football players that investigate the protective effect of performing repeated decelerations on subsequent performance of these actions, and the involved musculature, despite how common and important they are for performance and injury-risk mitigation in football. Therefore, the aim of this narrative review is to discuss the critical role of eccentric and decelerative training for muscle damage protection and recovery in football. The narrative review will provide recommendations on how eccentric and deceleration training can be implemented in both on and off field settings, during pre-season, in-season, and post-season periods, with particular emphasis on its implications for injury-risk reduction and performance enhancement in football. These recommendations may foster novel approaches to injury-risk reduction and the optimization of physical preparation strategies in football.

Neuromuscular adaptations to eccentric exercise

Eccentric muscle contractions are a common feature of daily motor activities and play a key role in two important aspects of natural locomotion: 1) the dissipation and absorption of mechanical energy during body deceleration and 2) the conversion of kinetic energy into the elastic energy stored in tendons [10]. Eccentric contractions differ from other types of muscle contractions in terms of the mechanical, metabolic, and neural responses and adaptations [10, 40]. Force application during eccentric contractions may be greater than the force generated by either isometric or concentric contractions [41]. Additionally, when applying force against the same relative load, EMG amplitude is usually higher during concentric than eccentric contractions. Eccentric exercise is more efficient, as concentric work at the same speed costs about six times more energy [10]. Likewise, eccentric-only muscle contractions induce positive shifts in muscle architecture with greater increases in fascicle lengths [42, 43]. This is reflected in the addition of serial sarcomeres following eccentric RT, with subsequent implications for performance and injury prevention because of a shift in the force–length and force–velocity relationships of the working musculature that may help to enhance force production and reduce the magnitude of muscle strain [11–13]. Similarly, when eccentric exercise is performed with high intensities and/or speeds, it is associated with greater increases in both total (average peak torque or 1 RM) and eccentric strength, as well as increases in the cross-sectional area and distribution of type II fibers in human skeletal muscle, compared to concentrically-oriented training [10]. Finally, greater satellite cell activity along with changes in the extracellular matrix (alterations in extracellular matrix gene networks and changes in connective tissue growth factor mRNA) have been observed after a single bout of eccentric compared to concentric exercise [44], suggesting that extracellular matrix remodeling may be a key factor in the muscle's structural response to eccentric versus concentric contractions [10]. These structural and neuromuscular adaptations may also have practical implications for injury prevention and rehabilitation in football. In support of this, additional eccentric hamstring training has been associated with a reduced incidence of acute hamstring injuries,

including both new and recurrent injuries, in male football players [45]. Moreover, eccentric training has been reported to reduce pain and improve function in athletes with tendinopathies [46].

Muscle damage from eccentric contractions

Eccentric contractions are a primary cause of EIMD, a transient impairment of muscle structure and function that typically occurs after strenuous or unaccustomed exercise, within athletic populations [14, 47]. Eccentric contraction generates mechanical stress on the muscle tissue, leading to its potential disruption, especially when the exercise is unfamiliar or performed with higher intensities, faster speeds or longer durations [10, 18]. EIMD resulting from eccentric contractions is characterized by several hallmarks that persist for days post-exercise. For instance, performing 30 maximal eccentric contractions of the elbow flexors has been shown to reduce strength by 34–40%, decrease ROM by 15–18%, increase arm circumference by 5% and increase delayed onset muscle soreness (DOMS), creatine-kinase (CK), and myoglobin levels [48, 49]. EIMD is associated with attenuation in muscular contractility, with impairments becoming more pronounced as the magnitude of EIMD increases [50]. Similarly, elevated CK levels, resulting from greater EIMD, may also impair performance, as they have been associated with reductions in external running load parameters (i.e., high-speed running distances, accelerations, decelerations, and maximal sprint velocity) in elite football players [51]. Therefore, prolonged EIMD can reduce physical readiness for future training, impair training quality and adaptation [52], and increase injury risk in semi-elite and elite football players [53].

Given the observed muscle function decline, relying on eccentric mono-articular muscle-damaging protocols hinders the relevance of EIMD research to football RT scenarios [54]. Multi-articular exercises and motor performance assessments are needed to bridge this gap. A systematic review and meta-analysis revealed that RT and plyometric exercises induced a significant increase in muscle damage, which impaired sprint, vertical jump and COD performance up to 72 hours [54]. Furthermore, markers of EIMD, such as changes in CK and DOMS were observed during the post-exercise period. Table 1 summarizes studies reporting post-exercise increases in EIMD-related parameters after repeated-sprint with enforced deceleration or COD training protocols. Collectively, these findings explain why the frequency of decelerations performed during competitive match play can be particularly sensitive to increases in EIMD post-match [55], leading to subsequent decrements in performance [37, 56–63] and increased susceptibility to injury [54]. Moreover, they highlight the potential protective role of athletes' training status against EIMD [54], underscoring the importance of how prior exercise exposure may modulate these responses [49]. Recent evidence further supports the notion that a greater eccentric capacity may protect athletes against the deleterious effects of repeated braking demands. Nakata et al. [64] reported that athletes with greater maximal eccentric strength exhibited a smaller decline in early-phase deceleration performance during repeated acceleration-deceleration tasks, whereas concentric strength was not significantly associated with this deterioration. Although direct markers of muscle damage were not assessed, the authors proposed that greater eccentric strength may reflect protective adaptations that reduce susceptibility to fatigue-related deterioration and eccentric muscle damage under repeated deceleration loads.

The repeated bout effect: Protection against muscle damage

Eccentric contractions induce adaptations that can enhance physical performance while also contributing to injury prevention. One of the benefits of eccentric RT is RBE. This phenomenon occurs when a single bout of eccentric contractions elicits adaptations that protect against EIMD in subsequent sessions of the same exercise [20]. These adaptations are characterized by faster recovery of strength and ROM, reduced swelling and DOMS and smaller increases in serum CK and myoglobin that may last over days possibly up to 6 months, compared to the initial exercise bout [18, 19]. Although mechanisms of the RBE remain to be fully elucidated, it is thought that mechanical, neural and cellular responses (or a combination of these) contribute to this protective effect in the muscle [18]. Table 2 provides an overview of studies that have examined the acute responses and RBE induced by different uni-articular eccentric resistance training protocols and repeated sprints with enforced decelerations. Unfortunately, most studies investigating the RBE utilize intensities based on maximum voluntary contraction (MVC), which presents practical challenges when prescribing traditional strength training with external overload. To translate these laboratory MVC values to the weight room, practitioners can use the rating of perceived exertion (RPE) and relative load prescription using %1RM, due to the direct relationship demonstrated between these parameters [65].

Due to the potential for significant EIMD and longer recovery times, the use of high-intensity eccentric RT protocols may not be beneficial in all contexts, particularly during competitive congested fixture schedules when recovery time is limited [54]. In well-trained football players, post-match recovery is outcome-dependent; although a substantial proportion of recovery occurs within 48–72 h, some neuromuscular, perceptual, and biochemical markers may still be altered at 72 h, and full recovery may require approximately 96 h [66]. Therefore, when matches are scheduled every 3–4 days, recovery time may be insufficient to tolerate additional high-intensity eccentric loading [48, 49, 67, 68]. Surprisingly, the use of submaximal eccentric exercise has also shown positive effects on the RBE (Table 2) [48, 67–70]. However, because of the lower effect, it is assumed that low-intensity eccentric exercise provides shorter-lasting protection against future maximal eccentric loads compared to maximal eccentric RT [49]. That said, the duration of the protective effect depends on players' training experience and the magnitude of EIMD in the initial bout. Additionally, the use of high-intensity on-field exercises or exercise situations involving multiarticular tasks, such as RT with external loads, plyometrics, straight and downhill running, linear sprinting, and sprinting with enforced decelerations, have also

TABLE 1. Post-exercise muscle damage indicators after repeated-sprint with enforced deceleration or change of direction training protocols.

Study	Sample	Protocol	Post-exercise impairments
Woolley, 2014 [61]	Physically active men (27.0 ± 3.0 years; 1.78 ± 0.06 m; 78.4 ± 7.5 kg)	Group 1: 10 × 10 Drop Jumps. Group 2: 40 × 15 m sprints with a 5 m deceleration zone.	↑ CK (72 h) ↑ DOMS (72 h) ↓ Wellness and performance test (72 h)
Howatson & Milak, 2009 [37]	Collegiate field-based team sports men (22.0 ± 2.0 years; 1.78 ± 0.06 m; 84.6 ± 13.6 kg)	15 × 30 m sprints with a 10 m deceleration zone	↑ CK (72 h) ↑ DOMS (72 h) ↓ Knee extensor isometric MVC (48 h) ↑ Swelling (48 h)
Keane et al., 2015 [58]	Premier league collegiate or national league field-based team sport women (22.0 ± 3.0 years; height: 1.66 ± 0.05 m; mass: 62.7 ± 4.5 kg)	15 × 30 m sprints with a 10 m deceleration zone	↑ CK (48 h) ↓ CMJ height (48 h) ↑ 30 m sprint time ↑ DOMS (72 h) ↔ Swelling ↔ Knee extensor isometric MVC
Thompson et al., 1999 [60]	Physically active men (23.8 ± 1.7 years; 1.78 ± 0.02 m; 77.2 ± 3.2 kg)	90 min of intermittent shuttle running and walking (Loughborough Intermittent Shuttle Test)	↑ CK (48 h) ↑ DOMS (72 h)
Grazioli et al., 2020 [57]	Well-trained male collegiate athletes (22.3 ± 3.2 years; 1.82 ± 0.08 m; 82.2 ± 10.7 kg)	15 × 20 m sprints with or without COD.	↔ knee extension MVC ↔ CMJ ↔ CK ↔ Quadriceps echo intensity ↔ Hamstrings echo intensity
Oxendale et al., 2025 [63]	Team sport athletes (8 males: 21.6 ± 2.2 years; 1.755 ± 0.08 m; 74.6 ± 8.5 kg; & 8 female: 21.8 ± 3.1 years; 1.66 ± 0.08 m; 60.6 ± 9.2 kg)	12 × [60" (175 m multidirectional running trial/ 120" (passive rest)]	↑ CK (48 h) ↑ DOMS (48 h)
Brown et al., 2016 [56]	Physically active women (19.0 ± 1.0 years; 1.64 ± 0.04 m; 58.6 ± 6.2 kg)	15 × 30 m sprints with a 10 m deceleration zone	↑ DOMS (72 h) ↑ CK (72 h) ↑ 30 m sprint time (72 h) ↔ Knee extensor isometric MVC
Leeder et al., 2014 [59]	Well-trained team-sports players (23.0 ± 3.0 years; 1.83 ± 0.05 m; 83.3 ± 9.7 kg)	Loughborough Intermittent Shuttle Test	↑ CK (48 h) ↑ DOMS (72 h) ↓ CMJ height (48 h) ↓ Knee extensor isometric MVC (48 h)
Khan et al., 2016 [62]	Male college soccer players (21.3 ± 2.0 years; 1.72 ± 0.07 m; 66.1 ± 11 kg)	15 × 30 m sprints	↑ CK (72 h) ↑ Swelling (48 h) ↑ ROM (48 h) ↓ CMJ height (48 h) ↑ 20 m sprint time (48 h)
Garcia et al., 2026 [81]	Trained/developmental male intermittent-sport athletes (25.0 ± 4.0 years; 1.80 ± 0.10 m; 76.0 ± 11.0 kg)	3 sets of 8 × 20 m DECfree vs DEC10 (10 m braking distance) vs DEC5 (5 m braking distance)	↑ CK (24 h) ↑ DOMS, greater in DEC5 (24–72 h) ↑ Rectus femoris stiffness, ↑ in DEC5 (48 h) ↑ Muscle thickness in DEC5 and DEC10 ↔ Pennation angle ↔ Fascicle length

CK: Creatine Kinase; DOMS: Delayed onset muscle soreness; COD: change of direction; CMJ: Countermovement jump; DEC: deceleration; MVC: maximal voluntary contraction; DJ: Drop Jump; ↑ Increased; ↓ Decreased; ↔ No change.

TABLE 2. Acute responses and repeated bout effect (RBE) induced by uni-articular eccentric resistance training protocols and repeated sprints with enforced decelerations.

Study	Sample	Bout 1	Post- 1ºbout outcomes	Bout 2	Post- 2ºbout. RBE outcomes	Time between muscle-damaging exercises
Uni-articular eccentric exercises						
Chen et al., 2009 [49]	Male university students (21.8 ± 1.9 years; 1.73 ± 0.06 m; 64.9 ± 9.2 kg)	30 maximal voluntary elbow flexor eccentric contractions at 90° s^{-1}	↑CK (+120 h) ↑ DOMS (+120 h) ↓ ROM (+120 h) ↓ Elbow flexor MVC (+120 h)	30 maximal voluntary elbow flexor eccentric contractions at 90° s^{-1} (there were 3 more bouts after bout 1)	↔ CK ↑ DOMS (96 h) ↓ ROM (96 h) ↓ Elbow flexion MVC (48 h) The largest RBE occurred after bout 1	Every 4 weeks
Chen et al., 2007 [67]	Male university students (20.7 ± 1.9 years; 1.73 ± 0.0 M; 67.6 ± 7.2 kg)	30 slow voluntary elbow flexor eccentric contractions using 100% MVC	↓ Elbow flexor MVC (+120 h) (> 60–40%) ↓ ROM (+120 h) (> 60–40%) ↑ Swelling (+120 h) (> 60–40%) ↑CK (+120 h) (> 60–40%) ↑ DOMS (+120 h) (> 60–40%)	30 maximal voluntary elbow flexor eccentric contractions at 30° s^{-1}	↓ Elbow flexors MVC (120 h) ↓ ROM (120 h) ↑ Swelling (120 h) ↔ CK ↑ DOMS (96 h) All parameters were less affected than after bout 1. 100% showed an index of protection > 60–40% for all parameters.	2–3 weeks apart
		30 slow voluntary elbow flexor eccentric contractions using 60% MVC	↓ Elbow flexor MVC (96 h) ↓ ROM (120 h) ↑ Swelling (120 h) ↑CK (96 h) ↑ DOMS (120 h)		All parameters were more affected vs. 100% but to a lesser extent vs. bout 1. No differences observed between 60% and 40%. 40% showed no protection in strength after bout 2.	
		30 slow voluntary elbow flexor eccentric contractions using 40% MVC	↓ Elbow flexor MVC (96 h) ↓ ROM (120 h) ↑ Swelling (120 h) ↑ CK (96 h) ↑ DOMS (120 h)			
Chen et al., 2012 [48]	Sedentary male university students (21.3 ± 1.6 years; 1.72 ± 0.05 m, 71.4 ± 9.9 kg)	(Control group) 5 × 6 maximal voluntary elbow flexor eccentric contractions at 30° s^{-1}	↓ Elbow flexor MVC (+120 h) ↓ ROM (+120 h) ↑ Swelling (+120 h) ↑ CK (+120 h) ↑ DOMS (+120 h)	5 × 6 maximal voluntary elbow flexor eccentric contractions at 30° s^{-1}	All parameters increased post-exercise, but recovery was faster when bout 2 occurred 2 days or 1 week after bout 1. When bout 2 was performed 3 weeks later, responses were similar to the control group	2 days, 1, 2 and 3 weeks apart
		5 × 6 slow voluntary elbow flexor eccentric contractions using 10% MVC	↔ Elbow flexor MVC ↔ ROM ↔ Swelling ↔ CK ↔ DOMS			
Coratella et al., 2025 [68]	Trained male adults (25.2 ± 2.9) years; 1.76 ± 0.08 m; 77.5 ± 11.2) kg)	4 × 6 slow Nordic hamstrings exercise	↓ Knee flexor strength (96 h) ↑ DOMS (96 h) ↓ ROM: (+96 h) ↔ Swelling	4 × 6 of the Nordic hamstrings exercise	↓ Knee flexor strength (24 h) ↔ DOMS ↓ ROM: (72 h) ↔ Swelling	4 weeks apart
Nosaka et al., 2005 [72]	Male students (20.3 ± 1.6 years, 1.70 ± 0.06 m, and 61.7 ± 8.7 kg)	2 × 24 maximal elbow flexor at 25º s^{-1}	↓ Elbow flexor MIF (+96 h) ↑ DOMS (+96 h; peak 24 h) ↓ ROM: (+96 h; peak 72 h) ↑ Swelling (+96 h; peak 96 h) ↑ CK (+72 h)	2 × 24 maximal elbow flexor at 25º s^{-1}	↓ Elbow flexor MIF (96 h) ↑ DOMS (72 h; peak 24 h) ↓ ROM: (96 h; peak 24 h) ↑ Swelling (+96 h; peak 24 h) ↔ CK	4 weeks apart

TABLE 2. Continue

Study	Sample	Bout 1	Post- 1ºbout outcomes	Bout 2	Post- 2ºbout. RBE outcomes	Time between muscle-damaging exercises
Multi-articular exercises						
Burt et al., 2013 [69]	Recreational active men (25.8 ± 4.1 years; 1.80 ± 0.09 m; 79.6 ± 9.9 kg)	10 × 10 Squats 80% body mass	↑ DOMS (+48 h) ↔ CK ↓ CMJ height (24 h) ↓ Knee extensor MVC (+48 h)	10 × 10 Squats 80% body mass	↑ DOMS (+48 h; > 50% recovery vs. bout 1) ↔ CK ↔ CMJ heigh ↔ Knee extensor MVC	2 weeks apart
Doma et al., 2015 [15]	Male recreational runners (24.0 ± 3.9 years; 1.83 ± 0.01 m; 77.4 ± 14.0 kg)	3 × 6 (squats, single-leg leg press, leg extension, and leg curls), 95% of 6RM load.	↑ CK (48 h) ↑ DOMS (48 h) ↔ ROM ↓ CMJ height (48 h)	3 × 6RM (squats, single-leg leg press, leg extension, and leg curls)	↑ CK (24 h) ↔ DOMS ↔ ROM ↔ CMJ height	2 weeks apart
On-field repeated sprint with enforced deceleration exercises						
Verma et al., 2016 [73]	Young male collegiate football players (18.0 ± 2.0 years, 1.63 ± 0.05 m, 55.0 ± 5.2 kg)	15 × 30 m sprints with a 10 m deceleration zone	↓ Knee flexor strength (+72 h) ↑ DOMS (+72 h) ↓ ROM: (+72 h) ↑ CK (+72 h)	15 × 30 m sprints with a 10 m deceleration zone	↓ Knee flexor strength (+72 h; > 50% recovery vs Bout 1) ↑ DOMS (72 h; > 50% recovery vs Bout 1) ↓ ROM: (48 h) ↑ CK (+72 h; > 50% recovery vs Bout 1)	2 weeks apart
Brown et al., 2016 [56]	Physically active women (19.0 ± 1.0 years; 1.64 ± 0.04 m; 58.6 ± 6.2 kg)	15 × 30 m sprints with a 10 m deceleration zone	↑ DOMS (+72 h) ↑ CK (72 h) ↑ 30 m sprint time (+72 h) ↔ Knee extensor isometric MVC	15 × 30 m sprints with a 10 m deceleration zone	↑ DOMS (72 h) ↑ CK (24 h) ↑ 30 m sprint time (24 h) ↔ Knee extensor isometric MVC	4 weeks apart

Bout: muscle-damaging exercise; RM: repetition maximum; MVC: maximal voluntary contraction; CK: creatine kinase; EIMD: exercise induced muscle-damage; ROM: range of motion; MIF: maximal isometric force, DOMS: delayed onset muscle soreness, CMJ: countermovement jump.

shown positive RBE [56, 71] and may also provide better performance transfer and protective RBE to high-intensity match activities such as decelerating [16]. Importantly, evidence from both maximal uni-articular exercises [48, 49, 67, 68, 72] and submaximal on-field [56, 73] or multiarticular exercise tasks [69, 70] indicates that a third bout of muscle-damaging activity does not provide additional recovery benefits compared with the second bout, suggesting that the primary biological adaptations underlying the RBE occur after the first exposure to muscle-damaging exercise [49, 71, 74].

While the protective benefits of the RBE through eccentric RT are well-established [18, 19, 75], there is currently a lack of deceleration protocols specifically designed to mitigate EIMD during future decelerations in training and competition [56, 73]. To the best of our knowledge, only two studies [56, 73] have investigated the potential of a deceleration specific running protocol to induce a RBE on a subsequent bout of repeated decelerations. Their findings demonstrated that 15 × 30 m sprints with a 10 m rapid deceleration reduced muscle soreness and markers of muscle damage (i.e., CK) following the same exercise bout performed four weeks later. In the following section, we present a theoretical framework to discuss the hypothesis that deceleration protocols may exert a prophylactic effect on the musculoskeletal system of athletes. Although scientific evidence is limited, biomechanical principles and the understanding of muscle adaptation suggest that such protocols may offer a protective role in mitigating EIMD during subsequent decelerations in both training and competitive contexts.

Using Deceleration Training to Mitigate Eccentric Muscle Damage

While accelerations have a higher metabolic cost [76], decelerations can elicit higher mechanical loading [25]. When performing a sharp COD, the forces observed when decelerating prior to the turn are typically greater than what is observed during acceleration [77]. This is also the case when performing a maximal horizontal deceleration from a maximal linear sprint [78]. In both instances, the braking steps have a unique ground reaction force profile characterized by high impact peak forces (~6 times body mass) and loading rates [78, 79]. Such high external forces must be counteracted by high internal muscle forces to generate the required joint extensor moments needed to resist and control joint flexion at the ankle, knee and hip [36]. For example, during the final braking step of

deceleration performed from a submaximal (75% maximal effort) sprint, quadriceps activation at peak knee flexion angles was significantly higher than those seen during maximal voluntary isometric contraction (161 ± 69%) [80]. Similarly, when performing a maximal deceleration from high sprinting speeds, the early braking steps impose high eccentric forces at rapid lengthening velocities, placing them at the greatest risk of muscle damage and fatigue [36]. The tibialis anterior can generate forces up to six times more than those observed during running and sprinting, while the gluteus maximus generates 2.5 to 5 times more [36].These findings help illustrate the substantial eccentric demands imposed during maximal deceleration and the potential for muscle damage and fatigue across the lower-limb musculature. Although eccentric RT currently has stronger supporting evidence, deceleration training may provide a more football-specific stimulus. Therefore, it should be viewed as a complementary rather than superior potential strategy for mitigating football-induced muscle damage.

The eccentric braking forces involved in decelerations can cause damage to soft tissue structures by creating high muscular tension, which may compromise the structural integrity of muscle fibers and lead to myofibrillar degeneration [38]. Intense decelerations have the potential to induce EIMD, as illustrated through the elevated levels of CK during the 72–h period following repeated sprints with intense decelerations [37]. Recent evidence suggests that post-sprint deceleration intensity may modulate local muscle responses beyond systemic biomarkers such as CK [81]. Repeated sprints followed by a more intense enforced deceleration (5 m) induced greater increases in rectus femoris stiffness and DOMS than moderate (10 m) or self-selected deceleration conditions, despite no between-condition differences in CK. This suggests that local muscle responses may be more sensitive than systemic biomarkers for detecting the effects of deceleration intensity [81]. Similar trends have been reported between the number of high-intensity deceleration actions and CK levels post-competitive match play in football players [82]. Deceleration-related injuries can result from long-term issues where tissue degradation outpaces tissue recovery [83]. Research found that a higher cumulative load of decelerations over 2–4 weeks increased the risk of overuse injuries [27]. This happens because repeated loading and activity cause damage to biological tissue, which builds up over time and exceeds the tissue's ability to recover and remodel. The slower recovery of passive musculoskeletal structures, which experience greater mechanical stress during deceleration actions, may result in chronic overloading and structural failure, leading to persistent injuries like stress fractures and tendinosis [28]. Sudden increases in workload, particularly during high-speed running, are commonly associated with muscular injuries, such as hamstring strains [84, 85], which may result from neuromuscular fatigue [86, 87] that has a shorter recovery time [88]. Nevertheless, few studies have found a clear connection between decelerations and injury in this context. Decelerations have been identified as mechanisms that are associated with non-contact ACL injury [89, 90], due to their propensity to generate high multi-planar knee-joint loading while the foot is planted [35, 91, 92]. That said, a field-based training intervention, comprising 2-weekly multidirectional speed sessions across 6 weeks, was effective in reducing surrogates of ACL injury risk [93]. Additionally, deceleration strategies emphasizing greater horizontal and posteriorly orientated forces appear effective for facilitating more effective deceleration, without concomitant increases in the loading of noncontact ACL injury surrogates [94]. Consequently, improvements in horizontal deceleration ability through targeted training exposures may contribute to reductions in ACL injury-risk. In addition, such exposures may induce RBEs that could help protect the athlete against the effects of subsequent bouts of intense deceleration maneuvers, although direct evidence remains limited.

Both the acute and the chronic physiological adaptations following field-based horizontal deceleration training are an area that warrants future investigation. For instance, recent work has shown improved sprint performance times and mechanics, as well as positive architectural shifts in the hamstring muscles (e.g., increased fascicle length), following high-velocity sprint training [95]. In this regard, questions exist as to whether similar outcomes would be observed following targeted horizontal deceleration training interventions. For example, due to the high eccentric demands imposed during braking [78, 79], coupled with the role of the passive structures within the muscle-tendon unit [38], it may be expected that positive structural and neuromuscular adaptations can be induced.

One of the main limitations associated with the prescription of deceleration exercise is the difficulty, or lack of practitioner knowledge, in accurately quantifying the intensity of different deceleration tasks. This is in contrast to traditional RT, where exercise intensity can be prescribed using relative loads such as %1RM. Deceleration tasks initiated from longer approach distances and higher sprinting velocities require greater deceleration distances, times and number of braking steps, with early braking steps characterised by single-limb support and very high impact peak forces and loading rates [77, 96]. Conversely, shorter sprint approach distances require deceleration to be initiated from lower percentages of maximal sprinting velocity thereby reducing the number of braking steps, as well as the overall deceleration distance and time to stop [96]. When deceleration tasks are performed in conjunction with COD, the angle of the turn further influences mechanical and neuromuscular demands. More acute COD angles (i.e., < 90°) are associated with lower deceleration demands and a greater reliance on maintaining velocity throughout the turn [33]. In contrast, during sharp COD tasks (i.e., 90°–180°), substantial braking is required over multiple foot contacts during the deceleration phase to momentarily reduce velocity to zero prior to executing the directional change [33]. Moreover, when horizontal decelerations are initiated with un-anticipated stimulus, braking demands are further intensified leading to increased forces and joint demands [96]. Figure 1 summarizes the potential benefits and drawbacks of performing horizontal deceleration exercises to induce RBE and key variables that can be modified

to adjust the type and intensity of horizontal deceleration. Examples are provided of how key variables can be manipulated to adjust the deceleration intensity (i.e., low to high).

Prescription of eccentric and deceleration training

The training and competition phases for football players are typically divided into three primary macrocycles: 1) the preseason, 2) the in-season (or competition) phase, and 3) the off-season phase [97]. Each of these phases has distinct goals, and the training loads are adjusted based on the players' physical fitness and well-being. Training load prescription is typically based on the time distance from competition. This period can range from several weeks (off-season) to just 3–4 days (in-season). Similarly, the training load strategy can be adjusted if the player is injured and will not be available to compete for a specific period. All these contextual factors can influence the dosing strategy for eccentric and decelerative exercises. Ultimately, the primary objective of this section is to propose the inclusion of isolated eccentric and deceleration exercises as a strategy that may help mitigate the muscle damage induced by the high eccentric and decelerative loads players experience during matches and routine seasonal training [36, 38]. This prophylactic approach is particularly crucial because most standard training sessions frequently incorporate small-sided games, which are inherently characterized by a high volume of intense decelerative actions [14, 25, 98].

Pre-season

The preseason phase aims to optimize players' physical and technical-tactical qualities [99]. Preseason competitions are mostly of a 'friendly' nature, allowing for player rotation during matches to ensure accumulating competitive and chronic load. Concurrently, high training loads are commonly prescribed to prepare players for the upcoming competition season [100, 101] and thus, to reduce the likelihood of injury during the competitive phase [101]. Since players come from a transitory period, sudden increases in load during preseason can lead to greater EIMD parameters [102]. In this regard, coaches may implement eccentric and decelerative training to induce RBE, thereby reducing EIMD and enhancing recovery following the high loads experienced during the preseason.

Currently, there is a lack of scientific evidence regarding the application and effectiveness of eccentric and deceleration exercises prescribed in 'real world' scenarios to achieve a RBE [1, 83]. A systematic review and meta-analysis reported no reduction in EIMD parameters across training blocks with consistent training loads [102]. This suggests that conventional training methods for inducing RBE may be ineffective for elite and semi-elite athletes. Although high-intensity eccentric exercises maximize RBE benefits, introducing them during the intensified early preseason is inadvisable, as they can elevate EIMD for up to 72 hours. A possible solution would be to employ moderate intensity eccentric loads, which induce smaller increases in EIMD markers while serving as a short- and medium-term prophylactic strategy [67]. The reader can refer to the information provided in Table 2 for a better understanding of the characteristics and effects of using different intensities of eccentric RT.

Importantly, it should be noted that, to identify specific training implications for achieving RBE, the exercise stimulus should replicate the muscle actions commonly used in football, that enhance resilience to eccentric forces under specific conditions. For example, sprinting has emerged as a vital element in conditioning for elite team sports, offering the dual benefit of enhancing performance while reducing injury risk [8, 85]. High-force and high-velocity eccentric contractions employed during sprinting strides elicit considerable physiological stress, manifesting a reduced performance potential and showing signs of RBE in certain parameters [73]. Unfortunately, there is only one study that provides evidence on the use of high-intensity horizontal decelerations to produce a protective effect against future high-intensity deceleration exposures and accompanying eccentric loads experienced by football players [73]. Due to the high eccentric demands of decelerations, we suggest that the implementation of controlled, moderate-intensity deceleration drills may help induce a potential prophylactic effect on the muscles involved in decelerations, although this remains to be confirmed experimentally. For this reason, it is paramount to monitor progressive exposure to decelerations. An optimal match play preparation should include incrementally progressive exposure to deceleration loadings [27]. Indeed, reduction of CK and associated detriments in neuromuscular performance may be possible when players have been accustomed to high-intensity decelerations [56]. Figure 2 presents a proposal for scheduling eccentric and decelerative exercises to capitalize on the RBE during the pre-season period. It should be acknowledged that the practical proposals shown in Figures 2–4 are based primarily on the established protective effects of eccentric exercise on EIMD, together with the mechanical similarity between eccentric loading and high-intensity deceleration actions. Direct experimental evidence supporting the effectiveness of deceleration-specific protocols to accelerate post-match recovery in football players remains limited; therefore, these figures should be interpreted as evidence-informed applied frameworks rather than as validated prescriptions.

In-season

During the competitive season, it is increasingly common for players to compete every 3–4 days, resulting in cycles of accumulating muscle fatigue, tissue damage and chronically elevated CK levels [38]. This will further diminish coordinative movement proficiency, which could negatively affect an individual's capacity to skillfully dissipate braking loads, leading to increased risk of tissue damage and injury [1]. The highly competitive load reduces the number of training sessions between matches, resulting in short-duration microcycles with lower external load, as they prioritize recovery and tactical preparation due to time constraints [103–105]. Training interventions should, therefore, focus on these key aspects to effectively protect the player against the EIMD of high eccentric loads that occur during competition [1]. For this reason, achieving RBE through eccentric exercise during these

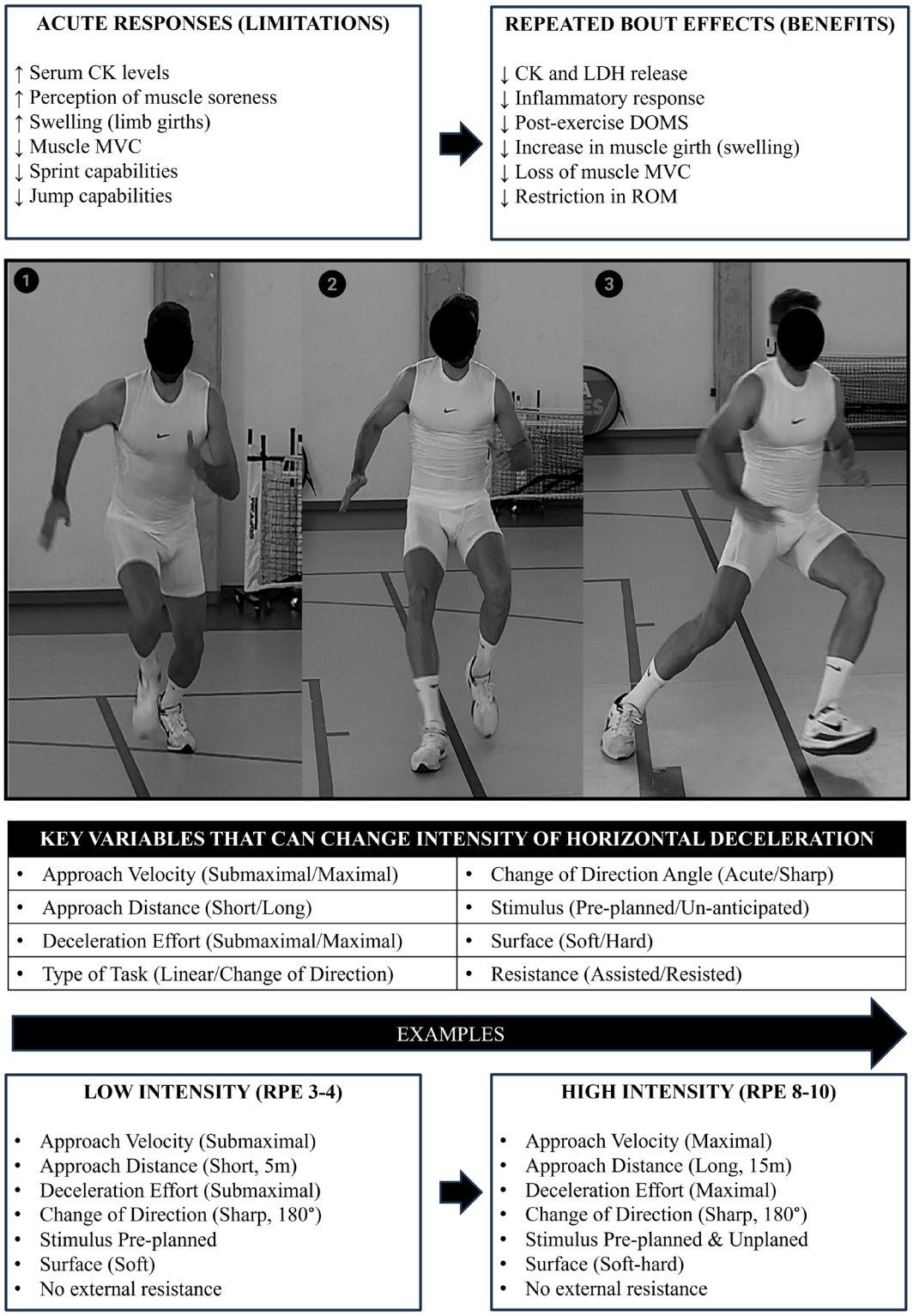


FIG. 1. Conceptual overview of the potential acute responses and RBE-related benefits associated with horizontal deceleration exercise, together with the main task variables that can be manipulated to modify deceleration intensity. The upper-left panel summarizes the expected acute responses after an initial unaccustomed or sufficiently demanding deceleration stimulus, including increases in indirect markers of muscle damage and transient reductions in neuromuscular performance. The upper-right panel summarizes the expected protective adaptations observed during a repeated exposure, consistent with the RBE, including smaller increases in muscle damage markers and smaller decrements in function. The central images illustrate the main phases of a deceleration task: 1, acceleration/approach phase; 2, braking phase; 3, change-of-direction maneuver. The lower panels summarize key variables that can increase or decrease horizontal deceleration intensity, including approach velocity and distance, deceleration effort, task type, change-of-direction angle, stimulus predictability, surface, and external resistance, and provide practical examples of how these variables may be combined to create lower- or higher-intensity drills. CK, creatine kinase; LDH, lactate dehydrogenase; DOMS, delayed-onset muscle soreness; MVC, maximal voluntary contraction; ROM, range of motion.

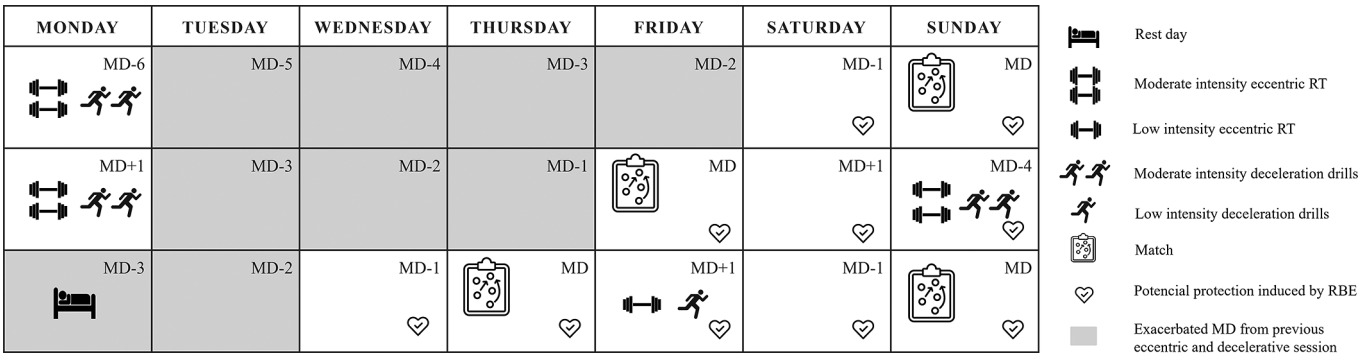


FIG. 2. Example of three different training microcycle during the pre-season of a football team. The RBE can be observed, as the first eccentric session induces 4 days of muscle damage, while in the second session, players recover more quickly, with muscle damage parameters accentuated for only 3 days. The low intensity eccentric training session does not induce alterations in muscle damage parameters.

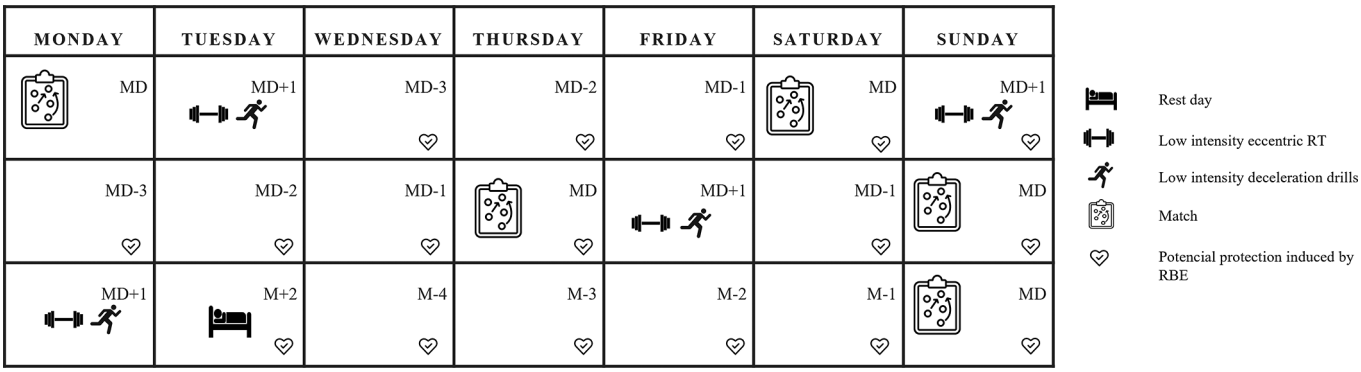


FIG. 3. Representation of 3 weeks of training during the in-season period of a football team. The low intensity eccentric training session does not induce alterations in muscle damage parameters.

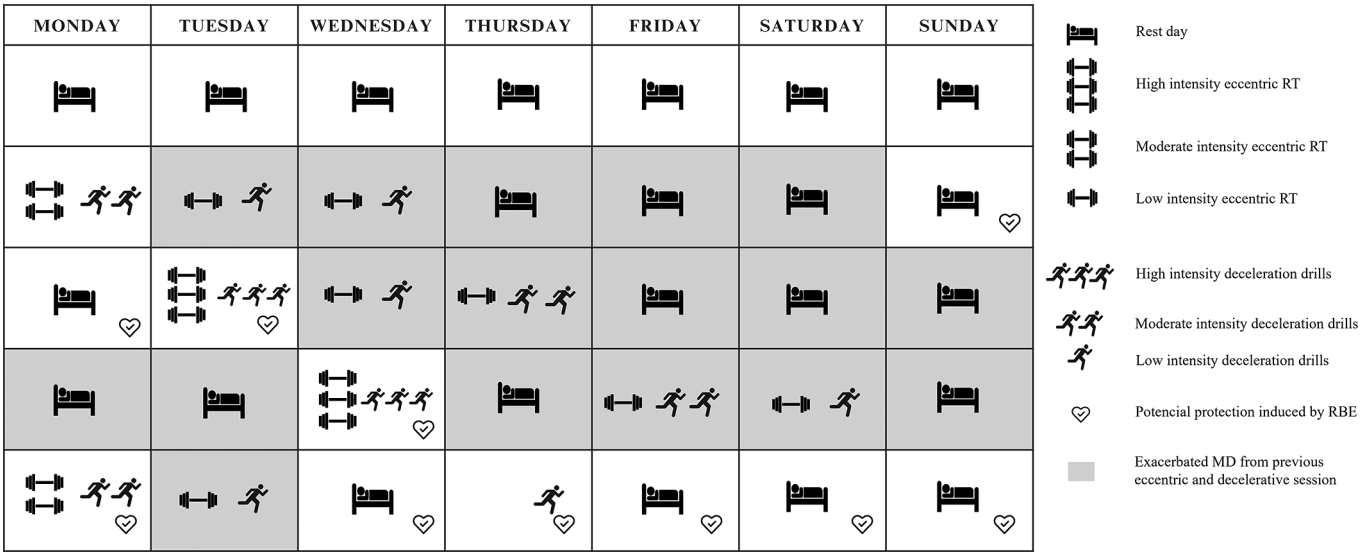


FIG. 4. Representation of 4 weeks during the off-season period of a football team. The RBE can be observed, as the first eccentric session induces 5 days of muscle damage, while in the second session, players recover more quickly, with muscle damage parameters accentuated for only 4 days.

congested periods represents a significant challenge for strength and conditioning specialists. Fortunately, eccentric exercise bouts do not need to cause noticeable symptoms of EIMD to elicit a protective adaptation [48]. Although it has not been demonstrated in elite athletes, evidence suggests that very low-intensity eccentric loading (Table 2) may be sufficient to elicit a RBE, thereby potentially attenuating EIMD associated with maximal eccentric exercise [48]. Also, small doses of eccentric exercise 24 hours post-matches have been shown to slow the rate of CK decay, without exacerbating soreness beyond the typical recovery time-course in professional football players [39]. However, since no EIMD occurs with low-intensity eccentric bouts, the protective effect lasts less than 2 weeks. Similarly, if the eccentric stimulus is not modified, the RBE tends to lose its potential after the first bout [71, 74]. Thus, whether targeting RBE through specific on-field exercises or strength training routines, the eccentric stimulus must be periodically modified. Thus, to promote RBE during competitive microcycles, the systematic and progressive implementation of microdoses of eccentric exercise, both on and off the field, may be considered. Figure 3 presents a proposal for how eccentric and decelerative exercises could be scheduled to take advantage of the RBE during the in-season period.

Off-season

The off-season involves a period of training cessation, with a significant or complete reduction in training and competitive load. A professional football player has an off-season period of 3–6 weeks, which leads to the onset of a detraining process, characterized by partial or complete loss of training induced adaptations [106]. Due to the absence of competition, the off-season provides the longest period of rest and recovery throughout the year. Here, players indeed may benefit from incorporating high eccentric loads to induce RBE. The use of high-intensity eccentric RT during a single session has been shown to significantly reduce EIMD parameters during a subsequent exposure to high eccentric loads [49]. The protective effect on the involved musculature may last from several weeks up to a maximum of six months [19].

During the final week of the training season, once season is over, fitness conditioning specialists should implement protocols based on high or very high-intensity eccentric and decelerative exercises for their players' off-season break. With an appropriate application of high-intensity eccentric and decelerative training stimuli, while respecting players' recovery, it is possible to induce a protective muscular effect against the high training loads they will encounter during the initial weeks of the upcoming preseason. Figure 4 presents an example to schedule eccentric and decelerative training to take advantage of the RBE during the off-season period.

Importantly, it is well recognized that resistance-trained subjects experience a significantly smaller RBE compared to untrained ones [54, 57]. Therefore, special attention should be given to the type of population targeted for RBE, as few studies have shown results in trained athletes. Falvo et al. [21] found no RBE in resistance-trained men, while Leeder et al. [59] reported minimal protection in well-trained athletes, possibly because the initial session lacked sufficient intensity to trigger RBE. Future studies should investigate this phenomenon more deeply in trained athletes and examine whether the effect is truly inferior in this population, or if a higher stimulus than that applied in physically active populations in previous studies is required.

CONCLUSIONS

This article highlights the potential benefits of eccentric RT and field-based horizontal deceleration training in football, emphasizing their roles in performance and mitigating injury risk. While eccentric RT is well-documented for its ability to reduce EIMD and aid recovery, particularly through the RBE, effectively achieving these adaptations requires an exercise stimulus that closely mimics the typical muscle actions during football practice. Although decelerations impose significant mechanical stress on muscles and contribute heavily to EIMD, there is currently insufficient evidence to confirm whether deceleration-based drills offer protective effects comparable to those of traditional eccentric RT. This gap underscores the need for further research. Future studies should experimentally replicate and adapt the eccentric exercise protocols previously used in EIMD and RBE research within football-specific contexts, with particular attention to their effects on EIMD magnitude and post-exercise recovery time course. In addition, studies are needed to determine whether field-based deceleration protocols can induce a RBE and attenuate subsequent football-related muscle damage. Importantly, these investigations should include players of higher competitive standard and greater training exposure, since it remains unclear whether current findings generalize to footballers who train daily and compete weekly. Consequently, integrating specific deceleration protocols alongside eccentric exercises may represent a useful evidence-informed strategy for safeguarding players, especially during congested periods of the season. To address this, the present article provides practical recommendations on how to implement eccentric and deceleration training in both on- and off-field settings across the pre-season, in-season, and off-season periods. By emphasizing injury-risk reduction and performance enhancement, these recommendations aim to foster novel approaches to the optimization of physical preparation strategies in modern football.

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