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Review

Eccentric Resistance Training: A Methodological Proposal of Eccentric Muscle Exercise Classification Based on Exercise Complexity, Training Objectives, Methods, and Intensity

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Abstract: Eccentric resistance training that focuses on the lengthening phase of muscle actions has gained attention for its potential to enhance muscle strength, power, and performance (among others). This review presents a methodological proposal for classifying eccentric exercises based on complexity, objectives, methods, and intensity. We discuss the rationale and physiological implications of eccentric training, considering its benefits and risks. The proposed classification system considers exercise complexity and categorizing exercises by technical requirements and joint involvement, accommodating various skill levels. Additionally, training objectives are addressed, including (i) Sports Rehabilitation and Return To Sport, (ii) Muscle Development, (iii) Injury Prevention, (iv) Special Populations, and (v) Sporting Performance, proposing exercise selection with desired outcomes. The review also highlights various eccentric training methods, such as tempo, isoinertial, plyometrics, and moderate eccentric load, each with different benefits. The classification system also integrates intensity levels, allowing for progressive overload and individualized adjustments. This methodological proposal provides a framework for organizing eccentric resistance training programs, facilitating exercise selection, program design, and progression. Furthermore, it assists trainers, coaches, and professionals in optimizing eccentric training's benefits, promoting advancements in research and practical application. In conclusion, this methodological proposal offers a systematic approach for classifying eccentric exercises based on complexity, objectives, methods, and intensity. It enhances exercise selection, program design, and progression in eccentric resistance training according to training objectives and desired outcomes.

Keywords: eccentric contraction; methodology; resistance training

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1. Introduction

Skeletal muscles represent up to 40% of an organism's body mass and are where nearly all the oxygen is consumed in the human body during maximum sustained effort. Remarkably, they are responsible for various essential functions, including locomotion, posture, endurance, ballistic movements, and thermogenesis, where skeletal muscle's phenotypic plasticity responds to the nature and magnitude of force-producing demands [1]. Regarding performance, in competitions such as the Olympic Games or World Cups, the differences between 1st (Gold) and 4th place (no medal) could be as small as ~1.5–2.0% for some sports such as rowing [2]. Therefore, the benefits that training (e.g., strength training) can deliver, even seemingly trivial ones, can be substantial in elite sports and health-related parameters.

Muscle actions modalities are represented as (i) isometric muscle action that involves no change in muscle length, (ii) concentric muscle actions that involve the shortening of muscle tissue, and (iii) eccentric muscle actions that implicate the active lengthening of muscle tissue against an external force or load [3]. In sports, rehabilitation, and physical activity, the rate at which eccentric actions are performed varies depending on the motor acts of the movement. Therefore, the ability to store, amplify, and attenuate muscular energy is essential to muscular health and allows for the development of efficient and effective training programs [4]. In almost any sport/discipline, movements involve concentric, isometric, and eccentric muscle actions. During eccentric work, the musculotendinous system lengthens and absorbs mechanical energy, which can be dissipated as heat. In this situation, the muscle functions as a shock absorber (energy attenuation). For example, in many sporting events involving landing, the body experiences high-impact forces, where the vertical ground reaction forces can reach values that exceed body weight by up to 14 times [5–7]. Therefore, the ability of the active musculotendinous system to dissipate mechanical energy can be essential in protecting passive anatomical structures [8]. In addition, in some sports, the ability to absorb high-impact acceleration varies vastly between good and inexperienced athletes. Other sporting examples in which eccentric action acts as a shock absorber include running downhill, landing movements in gymnastics, or decelerations in team sports, which can vary in duration, magnitude, and contraction speed [9].

During rapid and cyclic movements, the absorbed energy can be temporarily stored as elastic energy and used during an immediate concentric contraction. This phenomenon, called the stretch-shortening cycle (SSC), allows the muscle to act like a spring (an action linked to energy storage and amplification) [4]. The SSC mechanisms include neuromuscular pre-activation, stretch-reflex contributions, and the recoil of elastic energy stored in tendons [10]. The SSC is characterized by three phases (eccentric pre-stretch, amortization, and concentric shortening phases) [11]. The eccentric pre-stretch phase stretches the muscle spindle of the muscle-tendon unit and the non-contractile tissue within the muscle (series elastic components and parallel elastic components). The pre-stretch phase depends on the stretch's magnitude, rate, and duration. Manipulating these variables could substantially affect the energy stored during the eccentric pre-stretch action. The amortization phase represents the time from the cessation of the eccentric pre-stretch to the onset of the concentric muscle action. The shorter the amortization phase, the more effective and powerful the SSC movement because the stored energy is used efficiently in the transition. The concentric phase is the resultant power production performance phase and results from many interactions, such as the biomechanical response that utilizes the elastic properties of the pre-stretched muscles.

From a practical point of view, a fast and slow SSC can be determined depending on the eccentric-concentric contraction time [12]. Slow SSC occurs during jumps in team sports (e.g., volleyball, football, rugby), when angular displacement is high and ground contact time is long (>0.25 s). Fast SSC, e.g., in sprints, are characterized by less angular displacement and a ground contact time of fewer than 0.25 s. Effective SSC during sport-related movements is characterized by accentuated muscle pre-activation before landing, a short and fast eccentric phase, and a rapid transition (amortization phase) from the eccentric length to the concentric shortening phase during contact with the ground. Pre-activation increases muscle spindle sensitivity, improving the regulation of reflex potentiation and stiffness in eccentric phase [4]. Therefore, eccentric training planning will depend on the training objectives (performance or health-related outcomes) and the type of eccentric action (i.e., shock absorber or spring). To this end, it is crucial to consider the factors that determine the efficiency of different eccentric actions [4,10] (Figure 1).

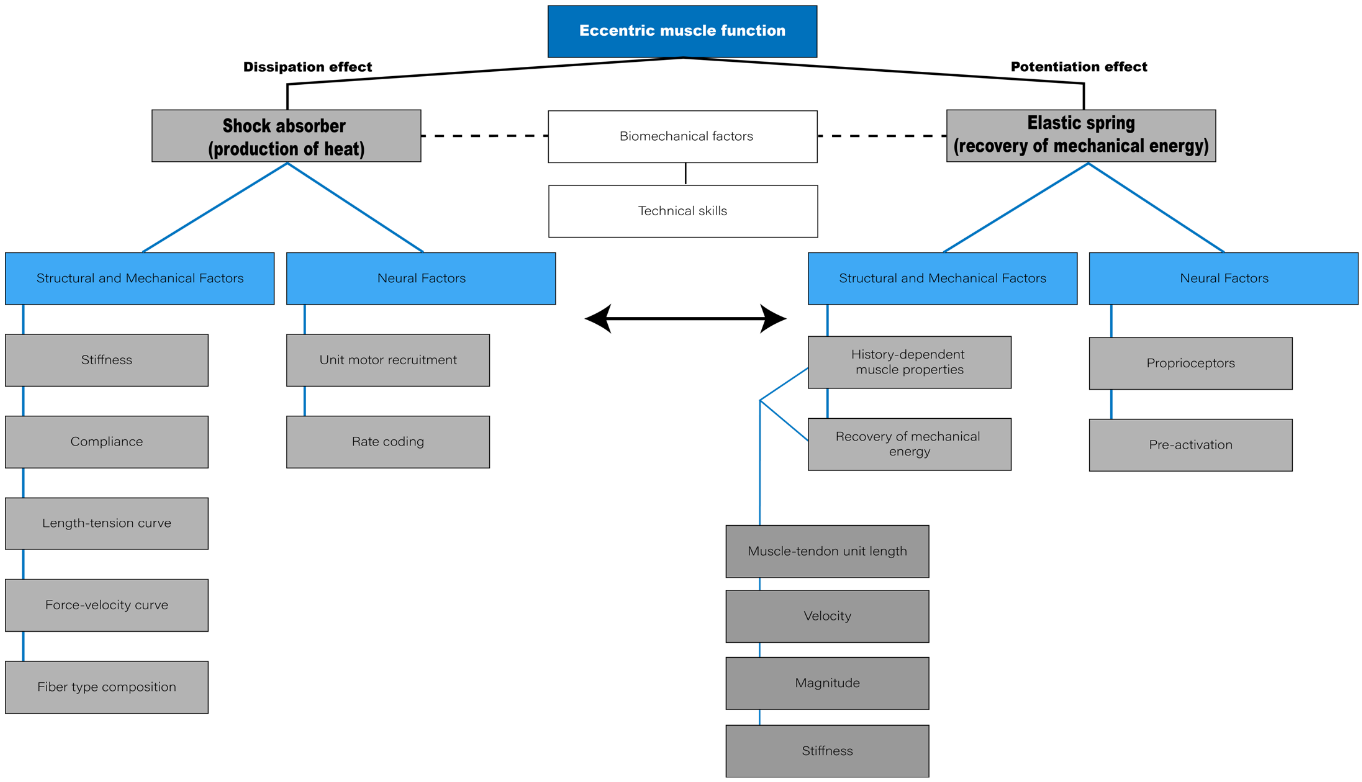


Figure 1. Underlying factors that influence eccentric muscle activity (adapted from [4,10]).

2. Characteristics, Benefits, and Risks of Eccentric Muscle Action

Eccentric exercise is considered a unique muscle action modality based on the active lengthening of muscle tissue. Muscles exposed to eccentric actions show a unique response compared to other types of muscle contraction and are characterized by the following (Figure 2):

1. A high force/tension ratio [3,13,14]. However, one study suggests that isometric actions could produce higher force values than eccentric actions exert force at an optimal joint angle [15].
2. A lower metabolic cost for muscular work produced at the same intensities as concentric muscular work (Figure 2B) [13,16,17].
3. Increased muscle strength in all forms of muscle contraction [18–20].
4. Selective regional hypertrophy and the architectural remodeling of the muscles, mainly in muscle length change [20–22].
5. Respond differently to the force/velocity curve, generating a mechanical paradox; the higher the execution velocity, the greater the force generated (Figure 2A) [13,19].
6. Rely on different morphological structures that support the eccentric action (e.g., titin, fascia, aponeurosis, and tendons (i.e., mainly connective tissue)) [23–25].

Considering all these factors, the muscle acts eccentrically as a shock absorber or elastic spring (Figure 1), where strength needs vary depending on the sport, motor activity, age, training level, health-related parameters, muscle strength capacity, training period, and rehabilitation phase [26–28]. Accordingly, their development and implementation require organization, structuring, and methodological control to guide training goals while considering their benefits and risks.

Eccentric training is broadly used in sports training to improve performance during eccentric tasks. The use of eccentric strength training enhances maximal muscle strength, explosive force (i.e., rate of force development), muscle hypertrophy, and muscular power, improving athletic performance [3,29]. Also, evidence supports its broad prescription in sports rehabilitation, notably in treating tendinopathies [30–33] and preventing/rehabilitating sports-related injuries such as muscle strain [34,35]. Additionally, since eccentric training provides high mechanical stress with low metabolic cost, it could be appropriate for training special populations with health-related problems such as muscle wasting and reduction in muscle strength, mobility, aerobic capacity, cardiorespiratory problems, sarcopenia, cachexia, type 2 diabetes, and neurological and musculoskeletal diseases [35]. Eccentric strength training implementation directly relates to training methods and desired adaptations (e.g., sporting performance and rehabilitation, muscle development, injury prevention, and special populations).

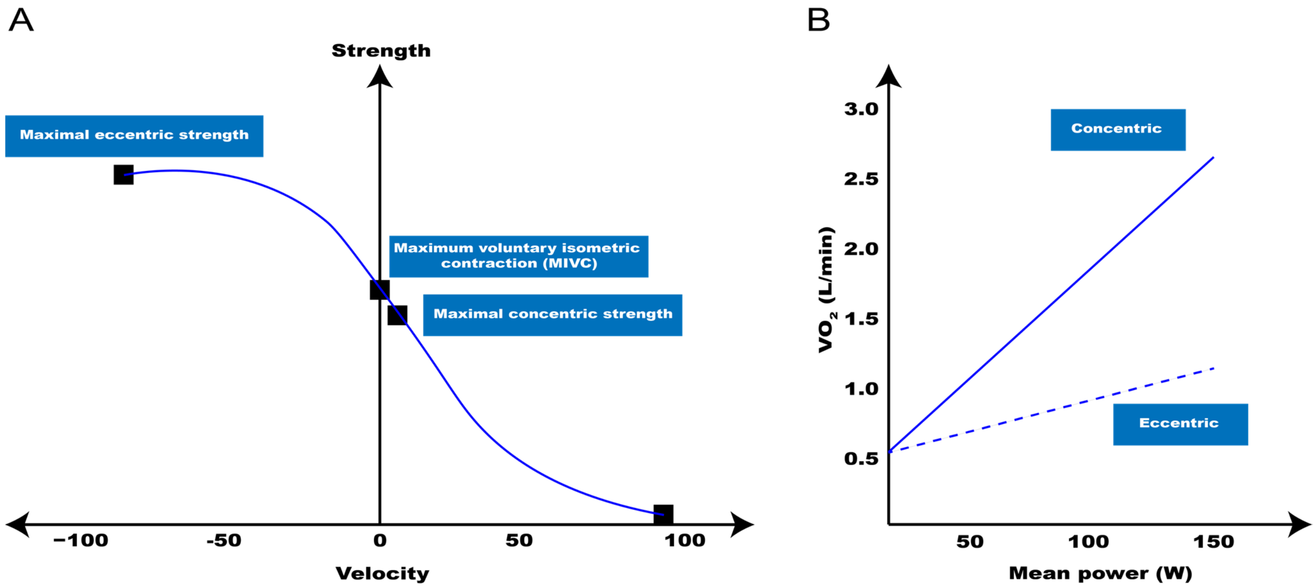


Figure 2. Distinctive responses of eccentric actions vs. other muscle contraction types (adapted from [3,13,14]). (**A**) The force-velocity curve that applies to the muscle action in eccentric and concentric phases. (**B**) metabolic cost (VO_2) according to the magnitude of work (mean power). VO_2: oxygen consumption. W: watts.

For young athletes in the early stages of muscle development, the stimulation of muscle strength through resistance training methods is essential [36,37]. The use of overloading in young athletes is paramount in developing strength and power qualities that support athletic performance, where the physiological adaptations that support such benefits are evident [36]. Similarly, a large body of evidence highlights the importance and efficacy of using eccentric overload methods to improve young male and female athletes' physical capacities [36,38,39]. Accordingly, the athlete's maturity stages, development, and technical learning of the exercises must be considered. Additionally, as with any other training modality, their training history, technical proficiency, and long-term physical development guidelines must be carefully considered [36].

Due to its specific physiological and mechanical properties, eccentric exercise is of great interest in rehabilitation processes of the muscle–tendon complex in special populations such as older adults or patients with chronic diseases (e.g., neuromuscular pathologies) [13,21,35,40]. Aging, obesity, chronic illness, physical inactivity, muscular unloading, and prolonged states of injury or rehabilitation affect the skeletal muscle and the tendon, causing quantitative and qualitative tissue alterations that affect muscle function and mobility [33,35,41,42], potentially exposing them to long periods of adaptation and recovery of their functions [33,35,43,44]. Consequently, eccentric training can be an alternative to counteract these effects in older adults or special populations; however, it is essential to consider multiple factors, such as modality, intensity, frequency/volume, and safety.

Eccentric exercise as a therapeutic model varies during the different phases of the muscle–tendon complex rehabilitation processes, and in terms of application, it is usually used as an injury prevention strategy in professional and amateur athletes [13,35,40,45,46]. The muscle–tendon complex interactions and adaptations related to mechanical load seem to be directed toward regional or specific responses by muscle or muscle groups [21,33,35,47]. Accordingly, muscle remodeling and the reordering of tendon collagen fibers are the basis of the therapeutic action of eccentric exercise [35,43]. Furthermore, eccentric mechanical work can treat tendinopathies since the tendon responds to mechanical forces by adapting its metabolism and structural properties, altering its genetic pattern, protein synthesis, and phenotype, which could improve the healing process [33,35,43,44].

Finally, training regimes should consider delayed-onset muscle soreness (DOMS). This muscular phenomenon generates a physiological alteration of the muscle's functional unit (the sarcomere). It presents structural and functional damage generated by applying excessive eccentric actions in sedentary people, young athletes, and athletes with little experience. It is a complex of symptoms, pain experienced upon movement, weakness, stiffness, and swelling of the muscles and areas of the muscle–tendon junction [48]. In addition, it can cause muscles to lose their functional characteristics, such as force generation or decreased proprioceptive function [35]. Multiple factors, such as muscle architecture, muscle phenotype, individual fitness, age, sex, and genetic variability, may contribute to the wide inter-subject variability in response to eccentric exercise [32,35,49,50]. Symptoms usually appear 8 to 10 h after work, reaching their highest peak after 24–48 h and progressively decreasing until total cessation after 3 or 4 days [40,51]. While an initial unaccustomed high-intensity eccentric exercise bout can induce a remarkable amount of muscle damage, the magnitude of this muscle damage is usually attenuated in the subsequent bouts of the same exercises (a phenomenon referred to as the repeated bout effect) [52]. Additionally, it is essential to note that low-intensity eccentric actions attenuate muscle damage induced by maximal eccentric actions [53], highlighting the relevance of managing different eccentric training methods and considering the different factors that constitute the training load (e.g., volume, intensity, rest, among others). Strength and conditioning practitioners should consider several factors in order to avoid these potentially undesirable associated effects, such as training experience, relative strength, the adaptations aimed during specific training phases, the progression of the complexity and technical requirements of the exercise, and the ability to integrate eccentric training into a holistic resistance training program to benefit a subject's overall performance.

3. Methods and Purposes of Eccentric Muscle Training

Although functions of eccentric muscle actions in biomechanics and strength training have been studied for decades, classification and evidence-based recommendations on implementing each eccentric method are lacking [3]. Nevertheless, eccentric muscle training methods can be grouped into seven types of work, differing in movement complexity, intensity, volume, technology, and time under tension:

1. Tempo [3,54].
2. Isoinertial [3,27,45,54–56].
3. Plyometrics [3,38,54,57].
4. Moderate Eccentric Load [13,30,58,59].
5. Accentuated Eccentric Load [3,54,60–62].
6. Isokinetic Dynamometry [3,54,63,64].
7. Eccentric Endurance [13,16,17,59,65–67].

These methods can be applied and combined according to rehabilitation phases, biological needs, or sporting requirements. When classifying eccentric exercises and methods, one should consider training objectives and movement complexity for practical and methodological purposes. Accordingly, the methodological proposal grouped the population into five large groups (Figure 3): (i) Sports Rehabilitation and Return to Sport, (ii) Muscle Development, (iii) Injury Prevention, (iv) Special Populations, and (v) Sporting Performance. Multiple factors, such as sporting level and needs, type of injury or illness, training period, age, and gender, determine its use and possible benefits [3,35,54].

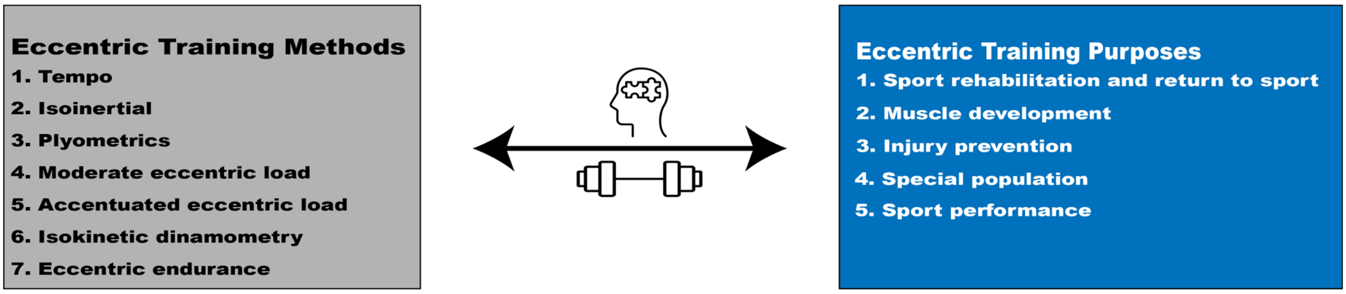


Figure 3. Reciprocal relationship between eccentric training methods and purposes.

3.1. Types and Classification of Eccentric Exercise

Different types of eccentric exercise rely on mechanical characteristics, metabolic cost, myotendinous unit compromise, and training purposes [4,18,19,29,68,69]. Franchi et al. state that eccentric exercise (with or without concentric phase and accentuated load) includes three different types of exercises: (i) eccentric exercises with constant speed (isokinetic), (ii) eccentric exercises with constant weight (isoweight), and (iii) eccentric exercises with constant inertia (isoinertial), with each one displaying diverse biomechanical patterns that result in different acute and chronic responses [69]. Also, Mike J. et al. propose a simple reasoning or classification based on concentric load intensity [18]. They divide the eccentric exercise into sub-maximal (less than 100% of concentric 1RM), maximum (100% of one repetition maximum concentric 1RM), or supramaximal (typically 105–140% of concentric 1RM), with the latter stimulating a greater increase in exercises involving both concentric and eccentric actions. Although this classification is helpful in clinical research, it is necessary to propose a broader and more accurate classification based on training purposes.

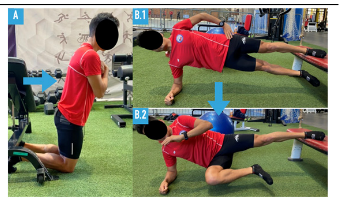
In practical terms, our proposal is based on concentric one repetition maximum (1RM), the rating perceived exertion (RPE), and exercise complexity (in single-joint and multi-joint exercises). Although 1RM testing must be controlled to safeguard the subject and the surrounding conditions, it is critical in determining accurate muscular workload [32,70–73]. This test must be implemented carefully in special populations and subjects without previous strength training experience. Thus, protocols and predictive equations for 1RM value are used successfully for these populations to avoid the challenge of direct 1RM testing. One repetition maximum can be accurately estimated in men, women, and special populations from multiple repetition tests, with five to ten repetitions being the most sensitive values for estimating 1RM [71–73]. To avoid excessive muscle damage and DOMS, which negatively affect participants' adherence and could harm those with pre-existing physical limitations [70,71], an adaptation period would be necessary before testing or estimating 1RM.

Our proposal adapts the 1RM classification, adding a sub-classification in the sub-maximal phase and considering the degree of complexity of the exercise, the RPE, and training purposes. The main classification is shown in Table 1. The complexity of the technical movement intersects with different stages of the subject's preparation or rehabilitation. Therefore, each type of eccentric exercise fulfills different functions according to those purposes. As a result, different methods and types of eccentric exercises can be used at different classification levels by modifying one or more load components (i.e., intensity, volume, rest, frequency) [4,54,69].

3.2. Determination of Intensity, Volume, Rest, and Frequency of Eccentric Exercises

The definition of resistance training load in the literature is still limited to the magnitude of the load, the number of repetitions and series, the rest between series, the number of weekly interventions, and the training period [74]. Nevertheless, this information complements our proposal to prescribe and control eccentric exercises.

Table 1. Methodological classification of eccentric exercises: balancing intensity and technical demand.

Eccentric Exercise Classification	Eccentric Training Methods	Eccentric Training Purposes	Example
Basic eccentric exercise	Tempo; Moderate Eccentric Load; Eccentric Endurance.	Sports Rehabilitation and Return to Sport; Muscle Development; Injury Prevention; Special Populations.	
Moderate eccentric exercise	Tempo; Moderate Eccentric Load; Eccentric Endurance; Plyometrics; Isokinetic Dynamometry.	Sports Rehabilitation and Return to Sport; Muscle Development; Injury Prevention; Special Populations; Sporting Performance.	
Submaximal eccentric exercise	Tempo; Isoinertial; Plyometrics; Isokinetic Dynamometry.	Sports Rehabilitation and Return to Sport; Muscle Development; Injury Prevention; Special Populations; Sporting Performance.	
Maximal and supra-maximal eccentric exercise	Tempo; Isoinertial; Plyometrics; Isokinetic Dynamometry; Accentuated Eccentric Load.	Sporting Performance; Muscle Development	

The choice of intensity is a critical factor in determining the results of training processes, ranging from simple to complex, easy to difficult, and low to high load. Furthermore, the RPE is used to complement the control and prescription of the intensity, determining the internal load of the exercise [75]. When eccentric exercise is related to concentric 1RM (sub-maximal, maximal, and supra-maximal), the intensity should range between 75 and 140%, and the rest between series should range from 45 to 240 s [27]. Lower load intensities also apply under specific rehabilitation and muscle development conditions. Recovery between exercises and training sessions also could impact RPE [76], modifying neural and metabolic responses [3,54]. Accordingly, rest redistributions (e.g., cluster set) could maintain peak force and velocity execution in different exercises [77–79], highlighting the relevance of controlling training intensity by managing different load components (e.g., load, rest), exercise complexity, and RPE.

Regarding the isoinertial method, low inertial loads allow greater concentric and eccentric power output, while high eccentric overload maximizes the eccentric/concentric ratio [27,80–83]. According to several studies, it is recommended that to maintain power output between series, 1 min rest is insufficient, 2 min rest allows one to maintain power output with light inertial loads (0.025 kg·m^2), and 3 min rest supports physiological recovery, especially when isoinertial loads are high ($\geq$0.075 kg·m^2) [27,80–83]. Concerning volume, there is a lack of research on the influence of this variable on acute and chronic responses following eccentric training. Generally, it is recommended to perform 3–4 series per exercise, 8–12 exercises per session, and 2–20 repetitions depending on the proposed purposes. These recommendations also are valid and reliable for the accentuated, moderate, and isokinetic eccentric methods [77–79,84].

Finally, the training frequency for eccentric exercise aligns with the guidelines proposed by traditional strength training models [85–89]. Eccentric training is prescribed as primary and complementary training one to three times a week with training periods of 4–24 weeks, depending on the selected training method [18,32,36,64]. The initial recovery from the first training session should take at least 48 to 72 h and be reduced as the athlete adapts to the training stimuli. Regarding sports context, eccentric training can be carried out before, during, or after the daily technical–tactical sessions and must be considered part of the training load (i.e., acute and chronic load) [3,39,54,56]. In the case of isoinertial training, although clear guidelines are lacking, research shows that 2–3 sessions per week completed for 5–10 weeks can sufficiently induce muscular adaptive effects [27]. Other aspects, such as experience, technical execution, and exercise order, must be considered.

3.3. Preparation, Execution, and Order of Exercises

Determining the athlete's or patient's experience and technical competence is essential. Athletes or patients undergoing eccentric training must have the support of an experienced advisor who can determine training loads and teach them the technical execution of the exercises. The latter is essential because the increase in eccentric strength depends on learning and the correct execution of movements (among others) [18,27,54,77–79,84,86,90,91]. Regarding exercise order, this should be related to the primary purpose of training [77,86]. For example, if the purpose is to increase strength in the lower limbs, exercises targeting the lower limbs must be executed in the first part of the session. In young/inexperienced athletes or athletes/subjects in rehabilitation, the order does not affect DOMS and the protective influences of the repeated bout effect. However, implementing a short period of muscular adaptation through low-intensity eccentric or isometric exercises has a substantial protective effect [53,84,92,93]. These recommendations are context-dependent and rely on the individual's objectives, physical capacity, and training status [78]. Finally, if the purpose is to increase strength and power, eccentric training should be performed before or in the first part of a technical–tactical session in team sports or in the first part of the training session for individual sports [4,27,94].

3.4. Execution Complexity of Eccentric Exercises

One essential variable that coaches and practitioners face when designing strengthening programs is the selection of exercises. Our classification proposal encompasses the complexity of the eccentric exercises (Figure 4). This complexity is closely related to eccentric exercise intensity, where the easiest or least complex exercises should start any eccentric training program. In addition, it integrates all previously described training load components (i.e., intensity, volume, rest, preparation, order, and technical execution), which could directly impact the subject's internal load [75]. The number of joints involved also aligns with exercise complexity. However, although multi-articular (multi-joint) or mono-articular (single-joint) exercises have many differences [88,95], there is no guideline indicating which is more appropriate for different purposes [96,97]. It should be noted that the sum of movements in multi-joint exercises generates greater complexity, increasing intensity [96,98]. Accordingly, exercise selection with different numbers of joints should be based on individual purposes and practical aspects, individual preferences, movement specificity, time commitment, and equipment availability.

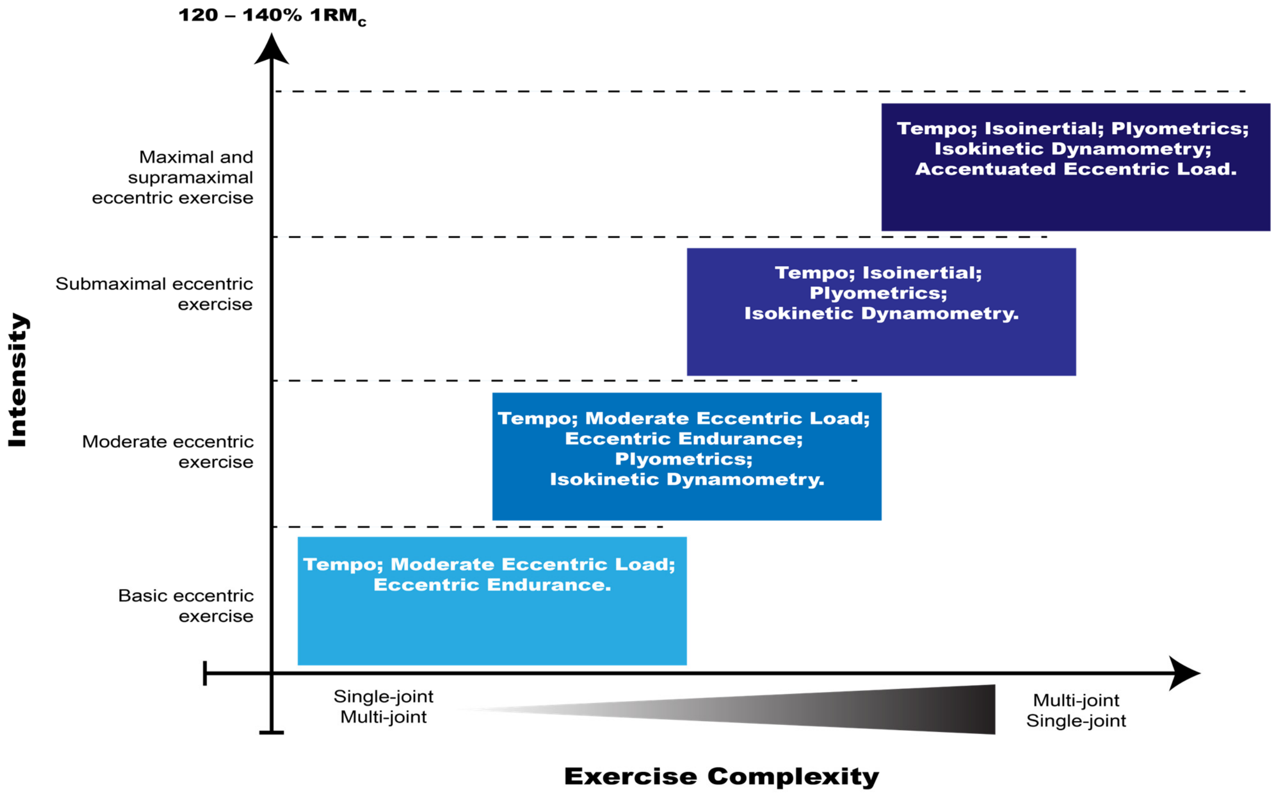


Figure 4. Understanding the interplay between eccentric exercise complexity and intensity. 1RM$_c$: one-repetition maximum in the concentric phase.

The exercise complexity is also associated with different equipment and technologies employed in eccentric exercise [3,19]. For example, a single-joint exercise in the knee extension machine could only be more complex if the intensity is increased at the eccentric phase. Thus, although single-joint exercises performed on machines are beneficial, they are less complex due to the lower technical and coordination demands [99,100]. Conversely, performing the one-leg variant in free weight or isoinertial exercises such as the deadlift could induce a greater demand in coordination, stability, and core activation (i.e., more complexity). As a rule of thumb, executing multi-articular exercises with high eccentric intensities would have greater complexity (e.g., free weights, isoinertial, isokinetic dynamometry, plyometrics), leading to them being classified in the most advanced phases of eccentric training [95–100]. Finally, exercise complexity is associated with the practice becoming less complex over time, creating a challenge for practitioners to modify the exercise training to achieve the desired effect.

4. Methodological Proposal: Classification, Characteristics, and Examples of the Proposed Eccentric Exercises

The methodological proposal is based on a % of the concentric 1RM (or % of body weight), complemented with exercise complexity and RPE described in dynamic strength exercises [101–103], and considers different aspects of eccentric training. Eccentric methods alone or combined with other modalities of muscular activation may have different implications for musculoskeletal system structures (e.g., tendon Young's modulus, muscle hypertrophy, or fascicle length changes) [33,104]. These responses/adaptations have different impacts on the eccentric action's functions (i.e., the shock absorption or energy attenuation functions, energy storage amplification or spring function, amortization phase) [4] and are influenced by factors such as the training level or age [33,104]. Therefore, eccentric training planning may depend on the population, the purpose of the training (e.g., training phase), the eccentric action that requires stimulation, and the adaptation process to training loads.

4.1. Basic Eccentric Exercise (Table 2)

Low-intensity eccentric exercise is recommended for subjects and athletes in phases of muscle development, injury prevention, rehabilitation and return to sport, and general adaptation processes. For example, these eccentric loads are essential for those returning to competition after suffering joint and muscle injuries such as anterior cruciate ligament (ACL) tears, hamstring tears, abductor/adductor tears, and quadricep strain [13,40,45,46,105]. It can also be applied to young athletes, older adults, and special populations (e.g., in metabolic/ventilatory/cardiac rehabilitation phases) [3,13,40,45,46,54,106,107]. In addition, several studies show the improvement of essential muscle physical conditions such as power output, speed, and the ability to sustain high-intensity efforts [106,107]. Injury prevention programs use eccentric loads, generating a broad consensus on the protection they confer on the muscles exposed to injuries during training and competition. The incorporation of eccentric exercises before, during, or after the main training session can significantly protect the adductor/abductor (e.g., Copenhagen exercise) and hamstring (e.g., Nordic Hamstring exercise) muscles. Regarding the latter, eccentric exercises have been shown to reduce hamstring injuries by up to 51% [108–110]. Both exercises exert a low to moderate level of eccentric loading when incorporated into training sessions. However, depending on the training level, these exercises could be perceived as moderate or sub-maximal loads, so their inclusion in a training program should be carefully analyzed.

Table 2. Suggested eccentric training at the basic level.

Intensity	Body weight, body weight (%) up to 40% of concentric 1RM [30,59], and RPE up to 4.
Objective	Sports Rehabilitation and Return to Sport; Injury Prevention; Sporting Performance [59,105].
Examples of exercise complexity	Basic single- and multi-joint human movement skills, low-impact plyometric and shock-absorbing movements, body weight load, and therapeutic exercises.

4.2. Moderate Eccentric Exercise [33] (Table 3)

Moderate eccentric load intensities support different processes such as muscular adaptation, advanced rehabilitation, injury prevention, and performance in the early stages of young athletes or those in lower-ranked competitive divisions [36]. However, this level must be cautiously implemented to prevent injuries or excessive DOMS [111]. Strength and muscle mass are critical to support performance in tasks that involve rapid changes in direction, vertical jumps, power output, sprints, and balance [36,74,112]. Skeletal muscle rapidly adapts to the damage from eccentric exercise to prevent further damage. The magnitude of the protective effect depends on variables such as load intensity, tempo, the total number of muscle actions, muscle lengthening, muscle groups, age, sex, and previous conditioning [52,53,84,92]. If muscle damage is unilaterally induced, the contralateral muscle also benefits from this protective adaptation [113]. The protective effect could be coordinated/influenced by neural and mechanical adaptations, selective hypertrophy, muscle architecture, extracellular matrix remodeling, and molecular adaptations [51,114]. Finally, examples of training methods at this stage include low- to medium-intensity plyometric work, box jumps, multi-jumps at small distances and heights, accelerations and decelerations, and moderate to sub-maximal eccentric overload with elements such as elastics, dumbbells, and bars.

Table 3. Suggested eccentric training at the moderate level.

Intensity	Body weight, body weight (%) up 40–60% of concentric 1RM and RPE between 4 and 6.
Objective	Sports Rehabilitation and Return to Sport; Injury Prevention; Sporting Performance.
Examples of exercise complexity	Basic to medium single and multi-joint, low to medium-impact plyometric and shock-absorbing movements, and balance exercises.

4.3. Submaximal Eccentric Exercise [115,116] (Table 4)

Eccentric exercises with greater loads are more complex, require previous strength training experience, and, sometimes, specific equipment. Isoinertial equipment (e.g., isoinertial pulleys and flywheels) was first introduced as exercise equipment for space travelers exposed to non-gravity environments [117]. With isoinertial devices, the movement begins with a concentric muscular action that unwinds the flywheel strap, followed by an eccentric muscular action that winds the flywheel strap, immediately producing the following concentric-eccentric cycles. The force applied in the eccentric action to stop the flywheel will depend on the kinetic energy generated during the concentric action and the strategy to apply the force in the last third of the eccentric muscle action [27]. Thus, the speed at which the strap is wound depends on the speed at which it is unwound. If enough force is applied during the concentric phase and resisted effectively in the eccentric phase, significant muscle overload can be achieved, improving and increasing muscle strength [80,118]. Isoinertial training can reportedly reduce injury severity during competition by up to 65% and lead to a substantial reduction in injuries per 1000 h of competitive play with respect to soccer; however, previous experience is essential in achieving these objectives [45,55]. Isokinetic dynamometers are complex equipment of high commercial value. Despite the continuous criticism against the limited information of exercise models in mono-articular muscle actions with constant velocity, isokinetic dynamometers are valid to reproduce eccentric muscle action with optimal neural control throughout a wide range of motion [69]. Isokinetic dynamometers also provide a highly reproducible measure of neuromuscular response in rehabilitation and muscular performance. Finally, parameters such as maximal force, mean force, power output, and angular work can be derived using relatively simple maximal or sub-maximal protocols [69].

This group of sub-maximal eccentric exercises also incorporates plyometric training, providing essential tools for performance development and final physical rehabilitation before one returns to competition [11]. Plyometric exercises are explosive movements that use the stretch–shortening cycle, where previous eccentric muscular action potentiates concentric muscle action. Its inclusion in strength programs is probably due to its ballistic nature and the ability to enhance power output and rate of force development (RFD) [112]. In addition, plyometric exercises for short periods (6–15 weeks) modify the stiffness of elastic components of the plantar flexor muscle–tendon complex in both athletes and non-athletes [57]. The mechanical and physiological responses to plyometric exercise and other training methods improve athletic performance (jumping, sprinting, agility, and endurance) and reduce injury risks in the lower limbs [38,57]. However, although plyometric exercise widely crosses the different intensities of eccentric work, high-intensity plyometric exercises require high levels of strength from the body parts involved [3,11,54].

Table 4. Suggested eccentric training at the submaximal level.

Intensity	Body weight, body weight (%) up 60–90% of concentric 1RM and RPE between 6 and 8.
Objective	Return to Sport; Muscle Development; Injury Prevention; Sporting Performance.
Examples of exercise complexity	Medium to complex single and multi-joint, medium- to high-impact plyometric and shock-absorbing movements, and competitive exercises.

4.4. Maximal and Supramaximal Eccentric Exercise [60–62,116,119] (Table 5)

Utilizing maximal or supra-maximal muscular loads through accentuated eccentric or tempo training methods requires performing the eccentric phase with a higher load than the concentric phase. Prescribing supramaximal loads (≥1RM) effectively improve maximal strength, which is crucial for sporting performance [112]. For example, maximal strength training in the lower limb extensor muscles (twice weekly) has been shown to improve vertical jump heights and 10 to 20 m sprint times in semi-professional and professional soccer players [120–122]. Maximal and supra-maximal loads induce high mechanical tension, stimulate the recruitment of high-threshold motor units, and involve changes in neuromuscular activity, the fibers' size and length, and the myotendinous junction's stiffness [29]. Finally, high-eccentric loads appear to induce a shift toward a faster athlete's muscular phenotype, in addition to associated functional adaptations that perform explosive movements [18,29,68].

Table 5. Suggested eccentric training at the maximal and supramaximal level.

Intensity	Body weight, body weight (%) up 90–140% of concentric 1RM and RPE ≥ 8.
Objective	Sporting Performance.
Examples of exercise complexity	Complex single- and multi-joint high-impact plyometric movements and competitive exercises.

5. Final Considerations

The decision to use different eccentric training methods together with other methods must consider factors such as (i) age, (ii) sex, (iii) sporting needs, (iv) competition stage or training level, (v) health status, (vi) training purpose, (vii) total time, and (viii) pre- and post-testing. Accordingly, an individual training plan must be generated with basic training principles, such as overload, individualization, progression, alternation, specificity, and periodization, in mind. According to our methodological proposal, the passage from one level to another considers the magnitude of the proposed intensity, applying the heaviest and more complex eccentric exercises in the final phases of training (Figure 5).

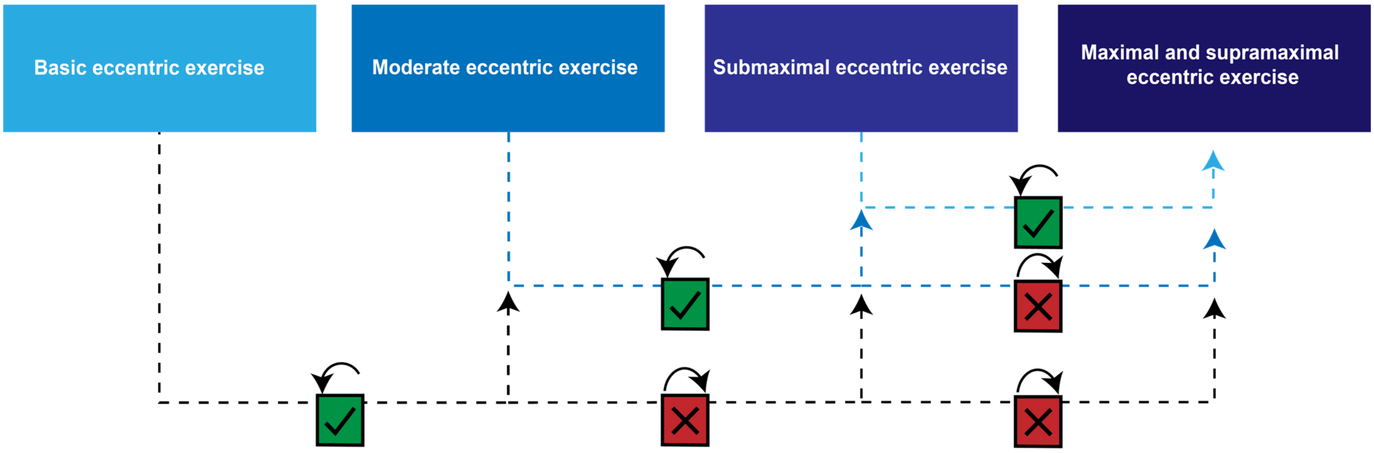


Figure 5. Blueprint for eccentric exercise application and progression.

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