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Eccentric load generation among different devices: narrative review with methodological approach

Generación de carga excéntrica entre diferentes dispositivos: revisión narrativa con enfoque metodológico

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ABSTRACT

This study presents a narrative review of the devices used to generate eccentric overload in muscle strength training, with an emphasis on their methodological differences, clinical applications, and effects on health. Eccentric loading, characterized by muscle contraction during muscle lengthening, has shown significant benefits for physical performance, injury prevention, and rehabilitation in athletes, clinical populations, and older adults. Despite its advantages, there is still a limited understanding of the different devices used, such as isokinetic, iso-inertial, electric, and pneumatic systems, each with specific characteristics regarding resistance type, applicability, and operational limitations. The comparative analysis shows that although all devices improve muscle strength and joint health, they differ in precision, portability, cost, and adaptability. Recommendations are provided for safe and efficient use, with priority given to individualized training. This work aims to serve as a foundation for future research focused on developing new, more accessible, and versatile technologies that optimize the use of eccentric loading across different contexts and improve sports performance and overall health.

KEY WORDS: eccentric training, resistance training, exercise equipment, sports performance, muscular rehabilitation

RESUMEN

El presente estudio realiza una revisión narrativa de los dispositivos utilizados para generar sobrecarga excéntrica en el entrenamiento de fuerza muscular, con énfasis en sus diferencias metodológicas, aplicaciones clínicas y efectos sobre la salud. La carga excéntrica, caracterizada por la contracción muscular durante el alargamiento del músculo, ha demostrado beneficios significativos en el rendimiento físico, la prevención de lesiones y la rehabilitación, tanto en atletas como en poblaciones clínicas y adultos mayores. A pesar de sus ventajas, existe desconocimiento sobre los distintos dispositivos empleados, como los isocinéticos, isoinerciales, eléctricos y neumáticos, cada uno con características específicas en cuanto a tipo de resistencia, aplicabilidad y limitaciones operativas. El análisis comparativo muestra que, si bien todos los dispositivos mejoran la fuerza muscular y la salud articular, presentan diferencias en precisión, portabilidad, costo y capacidad de adaptación. Se proponen recomendaciones para un uso seguro y eficiente, priorizando la individualización del entrenamiento. Este trabajo busca servir de base para futuras investigaciones orientadas al desarrollo de nuevas tecnologías más accesibles y versátiles, que optimicen el uso de la carga excéntrica en diversos contextos y contribuyan al mejoramiento del rendimiento deportivo y de la salud general.

PALABRAS CLAVE: entrenamiento excéntrico, entrenamiento de fuerza, dispositivos, rendimiento deportivo, rehabilitación muscular

INTRODUCTION

Muscle strength assessment is a fundamental pillar in both sports performance and rehabilitation. Understanding the body's ability to generate movement and energy through the biochemical mechanisms of muscle cells is essential for optimizing physical performance and accelerating functional recovery. This assessment is not limited to quantifying physical capacities; it also enables identification of how muscle strength directly influences injury prevention, improved functionality, and overall health in individuals of different ages and physiological conditions (1). In this context, overload training has been one of the most effective strategies for improving power, strength, and muscle mass. The stimulus intensity, determined by the mechanical load applied during exercise, plays a key role in the magnitude of physiological adaptations (2).

Despite the well-recognized importance of muscle strength, problems with physical performance persist across sports, rehabilitation, and general health. The lack of an appropriate approach to strength training or the inefficient use of existing methodologies may limit athletes' potential, prolong recovery processes in patients, and negatively affect the quality of life of the general population. This challenge underscores the need to explore and apply more effective and individualized training strategies (1, 3–5).

In this context, muscle strength training, especially eccentric-load training, has been proposed as a highly relevant strategy for improving muscle strength and power. This type of training focuses on the ability of muscles to generate tension while lengthening, offering unique benefits not only for increasing strength and power, but also for reducing injury risk and optimizing recovery. This training modality has represented a major advance in the understanding of muscle physiology and in its practical application to improve performance and health (6, 2). On the other hand, despite advances in eccentric training, there remains a significant lack of knowledge about the various devices available to generate these loads, their inherent differences, and the specific impact each has on overall health and performance. This information gap is critical, as it prevents coaches, athletes, and health professionals from making informed decisions about selecting the most appropriate and effective equipment for specific needs. Therefore, identifying and understanding these differences may not only optimize exercise prescription and programming but may also drive the development of new technologies that more comprehensively meet the demands of modern training and rehabilitation, helping to bridge gaps between research and practical application (7).

Muscle-strength exercises primarily involve three types of contractions: concentric, isometric, and eccentric, each with distinct mechanical and physiological properties that differentially influence muscular strength, power, and endurance (8–9). Concentric contractions involve muscle shortening while overcoming an external resistance, whereas isometric contractions maintain muscle length constant during contraction, thereby promoting joint stability, muscular balance, and fatigue resistance, and reducing the likelihood of musculoskeletal injuries associated with physical activity, exercise, and sport (10). However, eccentric contractions exhibit the greatest adaptive potential, as the muscle actively lengthens under load, generating higher levels of mechanical tension (1–2). This type of contraction, also known as negative contraction, plays a central role in the development of maximal strength, muscle hypertrophy, and injury prevention, while also improving the myotendinous unit's ability to absorb impact. Its strategic inclusion in training and rehabilitation programs has been a decisive factor in increasing strength and power, especially through devices designed to optimize eccentric overload. Because of their mechanical efficiency, lower energy cost, and proven functional benefits, eccentric contractions constitute the methodological core of this manuscript, which compares the devices that enable them and their characteristics and properties for inducing specific muscular adaptations through these contractions.

To this end, the reader will be guided through an exploration of the different types of muscle strength and the effects of eccentric loads on health. The most relevant characteristics of the devices that generate eccentric load, as documented in the literature, will also be described. Finally, recommendations for their safe use will be provided in order to maximize their benefits and minimize the risks inherent to this type of contraction.

For this purpose, a search of the specialized literature was conducted, focusing on existing devices that generate eccentric loads for muscle strength training, including their advantages and disadvantages, indications and contraindications, safe use, and their impact on health. The aim was to provide contextual information for the appropriate use of these devices and to identify characteristics and specifications for the development of new technologies based on eccentric overload, with an emphasis on accessibility, low cost, and, whenever possible, integration into existing machinery.

MATERIALS AND METHODS

This narrative review began with a search of scientific databases and literature resources, including Scopus, PubMed, ScienceDirect, Web of Science, and Google Scholar, using the keywords "Eccentric Strength" AND ("Devices" OR "Health" OR "Strength"). The inclusion criteria comprised open-access articles published in English or Spanish between 2019 and 2024. The data were analyzed and synthesized to identify differences among devices in effectiveness and health impact. Finally, conclusions were drawn based on the available evidence, and recommendations were provided for the appropriate selection and use of these devices.

BACKGROUND

Muscle force production results from a complex interaction between morphological and neurological factors that determine the musculoskeletal system's ability to generate mechanical tension efficiently. Structurally, one of the main determinants is the muscle cross-sectional area, as it is directly related to the number of sarcomeres arranged in parallel and, therefore, to the potential for maximal force generation (3). In addition, muscle architecture, including fascicle length, pennation angle, and fiber arrangement, significantly influences the force transmission capacity of the tendinous system (11). The stiffness of the musculotendinous tissue also plays a key role, since greater stiffness allows more efficient force transmission to the bony structures, whereas excessive stiffness may compromise energy absorption capacity and increase the risk of injury (8).

From a neurological perspective, force is modulated through motor unit recruitment, firing rate (activation frequency), synchronization among different motor units, and neuromuscular inhibition mechanisms. These factors largely depend on movement velocity, neuromuscular fatigue, and intermuscular coordination. The muscle's ability to absorb and dissipate kinetic energy, especially during eccentric contractions, also influences the efficiency of force production, as it involves fine neuromechanical control that balances external resistance with the integrity of the tissues involved. Together, these structural and functional components act synergistically to determine not only the magnitude of the force generated, but also its safe and effective application in training, competition, or rehabilitation contexts (1–2).

Moreover, in muscular manifestations such as the stretch-shortening cycle, the myotendinous unit releases elastic energy stored during muscle elongation in the concentric phase, in a manner similar to the extension of a spring. In contrast, when descending stairs at a normal pace, joint movement decelerates during the controlled descent, resulting in the loss of elastic energy as heat and acting as a shock absorber. The way muscles and tendons respond to these situations depends on movement speed, the force applied, and tissue stiffness (1), with eccentric contractions producing the highest levels of muscle tension, followed by isometric and, in turn, concentric contractions (8).

It has also been shown that training with a 40% greater load during the eccentric phase resulted in greater increases in maximal force production, endurance capacity, and muscle activation than traditional concentric-eccentric training with free weights. However, anabolic hormonal responses (testosterone, cortisol, and growth hormone) and hypertrophic effects were similar to those observed in conventional strength training (12).

In athletes, eccentric overload has been shown to improve performance, accompanied by increases in lean mass, muscle fascicle length, and the ability to absorb impact during activities involving high ground reaction forces, changes of direction, and jumping, with lower energy expenditure and reduced muscular fatigue (1, 6, 8).

Objective and subjective data have shown that current perceptions and practices of strength and conditioning coaches identify injury prevention, improvements in change-of-direction ability, strength and power development, injury rehabilitation, and muscle hypertrophy as the main reasons for including eccentric exercises in young athletes (13).

It is also noteworthy that eccentric training is an exercise modality with broad therapeutic applications, with precise indications according to injury severity, time since onset, the athlete's level of physical fitness, and the stage of rehabilitation (1). This is because eccentric loads are better tolerated, increase connective tissue tension, stimulate its regeneration, reduce fibrosis during healing, improve the capacity to absorb and dissipate energy during impacts and repetitive movements, and prevent degeneration due to immobilization, all of which are key aspects in rehabilitation (1, 8).

In conditions such as lateral elbow tendinopathy, eccentric training has been shown to promote tendon tissue remodeling by stimulating tenocytes, resulting in greater and improved synthesis of type I and III collagen, with the assistance of transforming growth factor-β-1 (TGF-β-1), insulin-like growth factor-1Ea (IGF-1Ea), and mechano growth factor (MGF). In this way, it improves pain and muscle strength during late-stage tendinopathy rehabilitation (14).

From a physiological perspective, eccentric exercise exhibits mechanical and neuromuscular characteristics that enable high force output with lower metabolic demand than concentric contractions. These properties promote structural adaptations in muscle and connective tissue, leading to their widespread use in rehabilitation programs and sports training contexts focused on strength development and injury prevention (15).

Its safe and effective use has also been demonstrated in older adults, as well as in patients with Parkinson’s disease and osteoarthritis. In this regard, sarcopenia and dynapenia, to which older adults are particularly vulnerable, can be effectively counteracted through eccentric training tailored to this population, improving not only muscle condition and functionality but also cognitive function, particularly processing speed and motor performance (1, 22).

For all these reasons, eccentric training is a viable option for adolescents, young adults, and older adults, provided that exercise prescription is properly adjusted to the objectives of the training program and to individual tolerability (1). However, despite its many benefits, it must always be implemented carefully and progressively, since it may cause greater muscle damage than other modes of strength training. For this reason, the devices that generate these overloads must be capable of accurately dosing and controlling the increase in overload, and this is precisely why such devices require special analysis (7).

Eccentric Training Methods

Suchomel et al. (3) highlight several eccentric training methods, each with specific characteristics and applications for optimizing muscular adaptations and performance. The main methods are described below:

Tempo eccentric training involves deliberately manipulating the duration of the eccentric phase of a movement. This means the muscle-lengthening portion is performed more slowly and with greater control than usual, thereby increasing time under tension during this phase. This method aims to maximize mechanical stimulus to the muscle, potentially leading to greater gains in muscle hypertrophy and strength. By prolonging the eccentric phase, controlled muscle damage is increased, which in turn stimulates a greater adaptive response, including muscle tissue growth and remodeling (1).

Flywheel training uses the inertia of a rotating flywheel to generate eccentric overload. Unlike traditional weights, which provide constant resistance, flywheel training provides variable resistance proportional to the user's applied force. During the concentric phase, the user accelerates the flywheel, storing kinetic energy. During the eccentric phase, the flywheel returns that energy, and the user must resist the force produced. This allows for significantly greater eccentric overload than concentric load, since the muscle must decelerate a moving mass. This method is highly effective for improving strength, power, and muscle hypertrophy, and has been shown to benefit sports that require high-intensity actions, such as jumping, acceleration, and deceleration (4, 7).

Accentuated eccentric loading refers to the application of a greater load during the eccentric phase of a movement than during the concentric phase. This can be achieved in several ways, such as using devices that add weight only during the lowering phase—for example, machines with weight-release mechanisms—or by having a partner apply additional load during the eccentric phase. The goal is to specifically overload the eccentric phase in order to take advantage of the muscle's greater capacity to generate force during lengthening. This method is particularly useful for improving maximal strength and power, as it exposes the muscle to higher tensions than it could tolerate during a concentric contraction (2).

Plyometric training is based on the stretch-shortening cycle (SSC), which involves a rapid eccentric phase immediately followed by an explosive concentric phase. This type of training aims to improve muscular power and the ability to generate force rapidly. During the eccentric phase, the muscle is stretched and stores elastic energy, which is then released during the concentric phase to produce a more powerful movement. Common examples include jumps, rebounds, and throws. Plyometric training is essential for sports that require explosive movements and has been shown to effectively increase muscular power (1).

Isokinetic dynamometry (IKD) is considered the gold standard for measuring the eccentric force generated by muscles during movement at a constant velocity. This methodology requires the use of devices such as Cybex, KinCom, Biodex, and Primus, among others, whose main drawbacks are high cost, maintenance requirements, and limited portability, limiting their use in exercise and rehabilitation centers (17–18).

Another device is the Hamstring Solo Elite (HSE), a Nordic hamstring exercise (NHE) device based on pressure-feedback technology that uses a load cell to monitor and improve muscle strength and muscle length, in this case of the hamstring muscles, with good relative intra-session reliability and acceptable inter-session reliability (19–21). Wiesinger et al. (18) stated that hip movement control must be carefully monitored when using this type of device, since hip position can significantly alter eccentric force. They also noted that current devices are not sufficiently precise to reliably determine the angle of peak torque and the strength imbalance between both lower limbs, meaning that only large changes in eccentric strength can be detected, whereas subtle variations in this type of measurement may go unnoticed (18).

Another device is the Smart Nordic Trainer dynamometer, which offers portability. It is designed with two load cells to measure the force applied by each lower limb, with a maximum capacity of approximately 500 kg. Compared with isokinetic dynamometers, its cost makes it more accessible. It is also very easy to use, as the device can record data via Bluetooth at 180 Hz, enabling immediate data acquisition during exercise. However, it may allow a certain margin of error in measurements during exercise (5–8 degrees) (23).

Iso-inertial and Electric Devices

Flywheel resistance training machines offer the potential to generate substantially greater additional eccentric load than can be achieved with constant weights against gravity. However, this occurs only during very small intervals of the movement phase and is not always achieved (25). YO-YO Technology and Versapulley flywheels are two examples of devices designed to generate eccentric overload by using inertial flywheels specifically during the eccentric phase of movement, thereby producing additional resistance during the range of motion in which the flywheel returns (4, 16).

González and Sánchez (4) mention four devices used for strength training in soccer players, including the Yo-Yo hamstring curl, which has shown good results in improving concentric and eccentric hamstring strength; the Yo-Yo squat and the Yo-Yo leg curl, both of which have been shown to improve countermovement jump performance and sprint time; and a vibration platform device with similar effects, which additionally improves change-of-direction ability, jumping performance, and power.

Regarding these devices, which are based on James Watt's industrial flywheel from the Industrial Revolution, Wang et al. (16) reported greater effectiveness of training with these devices compared with conventional training for improving strength, power, and muscle trophism in elite female volleyball players.

Their mechanism relies on applying a concentric force to unwind a rope or strap connected to the flywheel's central shaft, causing the flywheel to rotate and store energy. The rope then begins to rewind, and the participant must attempt to brake the movement by resisting the device's pull, thereby generating an eccentric contraction. Thus, the resistance experienced by the athlete depends on the device's mass, radius, and angular acceleration (4, 3).

It is particularly important to note that, with these devices, low moments of inertia (0.01 to 0.2 $kg \cdot m^2$) and cylindrical shafts should be used to achieve eccentric overload, since a conical shaft has greater effects on the concentric phase (4).

Iso-inertial devices have been widely used in strength training in team sports such as soccer, basketball, rugby, handball, and volleyball, in which players perform high-intensity actions, including jumps, accelerations, decelerations, linear sprinting, and changes of direction (4, 16).

Flywheels have shown positive effects on increasing muscle mass and improving jumping performance, linear sprinting, and changes of direction (acceleration-deceleration), thereby helping to prevent sports injuries associated with these movement patterns. These devices have also been proposed to improve maximal strength, power output, and running speed in both athletes and previously untrained individuals (4, 16).

These devices are extremely versatile and allow a wide variety of exercises to be performed in different planes of movement. Their portability makes them ideal for multiple settings, offering flexibility and convenience for training in a variety of environments (2, 3).

It should be emphasized that concentric velocity and inertial loads must be directly proportional to each individual's strength. This means that the greater or lower the individual's strength, the greater or lower the velocity will be, respectively. In addition, prior experience with flywheel devices may modify the stimulus required to achieve the desired effects. Therefore, it is important to individualize each exercise by adapting both velocity and load to each person's specific needs and capabilities (2, 3).

Despite the multiple benefits of these flywheels, they must be used with caution, prioritizing appropriate training and recovery periods. Otherwise, they may lead to reductions in maximal isometric strength and increased fatigue and muscle damage, particularly when players begin using these devices without adequate instruction or guidance (4).

Maroto-Izquierdo et al. (6) compared the effects of flywheel devices with those of an electric motor device. After 6 weeks of training, results showed similar gains in muscle mass, strength, power, and vertical jump performance, with no significant differences between the training groups. However, it is important to note that the group trained with the electric motor at an eccentric velocity of 150% showed greater gains in power compared with the group trained at an eccentric velocity of 100% and the flywheel group. Likewise, it has been shown that eccentric overload generated by flywheel devices elicits greater adaptations in strength, power, hypertrophy, and running speed than traditional strength training (6).

For its part, the electric motor is capable of generating eccentric overload throughout the entire range of motion; it does not require shortening the active braking phase in order to apply overload; and it allows the training stimulus to be modified by adjusting the intensity of the different forces, the transition time between phases, and the eccentric velocity relative to the concentric velocity, although its maximal power is limited (6). In contrast, the flywheel offers greater exercise possibilities in any plane of motion, although eccentric overload occurs only at the end of the range of motion, and there are limitations on modifying loads and eccentric velocity relative to concentric velocity (6).

Eccentric training with an electric motor has also been shown to improve squat jump height and the cross-sectional area of type II fibers, together with a transition toward faster myosin heavy chain isoforms after 10 weeks of training (6). Finally, Reyes-Ferrada et al. (25) described these electric devices as reliable for assessing trunk extensor strength under different velocity conditions and ranges of motion. However, their high acquisition and maintenance costs make them difficult to access. In addition, their large size limits their use in non-clinical settings or in spaces with limited room.

Pneumatic Devices

In 2020, Harden et al. (24) conducted a 4-week study to evaluate the impact of strength training with augmented eccentric loading using a novel pneumatic leg press device. The study included twelve well-trained athletes, randomly assigned to three groups: 1) traditional resistance training, 2) augmented eccentric loading training, and 3) full-time professional sprint track cyclists, who combined augmented eccentric loading with their usual training.

This novel leg press device overloaded eccentric muscle action during bilateral joint movement by using compressed air to provide resistance during exercise. Its features enabled measurement of maximal concentric and eccentric forces, allowing training to be directed toward each type of contraction and thereby ensuring task specificity (24).

Its operation is based on pneumatic technology, using magnetically operated adjustable reed switches to enable immediate unloading of the concentric phase of the movement. Force is measured using four load cells with a limit of 300 kg per cell, equipped with potentiometers (Hybritron®, 3541H1-102-L, Bourns, Mexico) at 200 Hz, located on the footplates and connected to a combiner that generates a single voltage output (24). To standardize the pace of the eccentric phase, an LED strip was added to the leg press; as it progressively illuminated, it left a light trail that the participant had to follow until reaching the displacement at which a 90° knee angle was achieved.

The results of this study showed that eccentric loading increased lower-limb muscle strength and was well tolerated, supporting its inclusion in athletes' training programs. Overall, the traditional method was effective under maximal concentric and isometric contraction conditions, whereas augmented eccentric loading stimuli increased not only maximal strength but also the expression of force during eccentric contractions (24).

Table 1 summarizes the devices used to generate eccentric loading, along with their advantages, disadvantages, and applications.

Table 1. Main characteristics of isokinetic, iso-inertial (flywheel), electric, and pneumatic devices.

	Ventajas	Desventajas	Aplicaciones
Isokinetic, constant velocity	Precision, Velocity control, Adaptable, Portable only in some models	Unable to detect small changes in force, Non-constant load, Single-joint assessment, Operational complexity, high cost	Injury prevention, Post-surgical rehabilitation, Training monitoring
Iso-inertial, variable resistance	Unlimited resistance, Portable, Versatile, Large range of motion	Depends on concentric velocity, Operational complexity in achieving the intended outcome	Team sports, Muscle strengthening, Injury prevention
Electric, adaptable resistance	Personalized resistance, Real-time feedback and monitoring, Large range of motion	Limited resistance, Dependence on electricity, High cost, Large size, Operational complexity	Neurological rehabilitation, Monitoring of athletic progress, Injury prevention
Pneumatic, adjustable resistance	Lightweight, Safe, Lower impact, Bilateral assessment, Specific and individualized	Lower precision, High cost, Maintenance requirements, Large size, Operational complexity	Rehabilitation, Low-impact training, Injury prevention

Recommendations for Safe Use

In most of the studies on eccentric loading analyzed, appropriate use of the devices requires avoiding any intense strength training for at least 24 hours before assessments or training sessions. Contraindications include recent muscle or joint injuries, cardiovascular disease, and the use of stimulants or depressants such as caffeine, alcohol, or drugs intended to enhance physical performance.

All tests should always be performed at approximately the same time of day (± 2 h) as the previous one, and should include a prior warm-up, preferably demanding at both the cardiovascular and muscular levels, followed by stretching, whenever possible, ballistic in nature, to prepare the muscle for eccentric contractions. Familiarization sessions with the devices are also recommended, without generating maximal stimuli, in order to prepare the musculature for this highly demanding type of contraction. Likewise, it is important to include rest periods of 1 to 2 minutes and verbal instructions to reinforce technique during testing and in each repetition. Additionally, to obtain better results, it is recommended to exclude repetitions in which participants show poor movement control and even to stop assessments or training if good technical execution of the required movement is not observed (18–19).

CONCLUSIONS

Eccentric overload exercise is a fundamental and highly effective tool for optimizing athletic performance. Its ability to generate higher levels of muscle tension and promote superior physiological adaptations, such as increases in maximal strength, power, and muscle hypertrophy, makes it an essential component of training for sports participants and elite athletes. The strategic implementation of eccentric loading directly contributes to improving movement performance, preventing injuries, and increasing efficiency in high-intensity sport actions. Likewise, eccentric overload has emerged as a highly valuable therapeutic modality in rehabilitation. Its effectiveness lies in its ability to stimulate connective tissue regeneration, reduce fibrosis during healing, and prevent degeneration from immobilization, all of which are decisive factors in the recovery from musculoskeletal injuries.

Additionally, eccentric overload training offers significant benefits for overall musculoskeletal health and is particularly relevant for health promotion in specific populations, such as older adults. Given that eccentric strength tends to be better preserved with aging than concentric strength, this modality represents a therapeutic focus for combating sarcopenia and dynapenia, thereby promoting active and healthy aging. Nevertheless, there remains a need to develop accessible, versatile devices that enable precise load dosing to maximize these benefits and ensure safe use by the general population.

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