Flywheel Eccentric Training: How to Effectively Generate Eccentric Overload

Eccentric resistance training has been shown to elicit beneficial effects on performance and injury prevention in sports due to its specific muscular and neural adaptations. Within the different methods utilized to generate eccentric overload, flywheel eccentric training has gained interest in recent years due to its advantages over other methods such as its portability, the ample exercise variety it allows as well as its accommodated resistance. Only a limited number of studies that utilize flywheel devices provide enough evidence to support the presence of eccentric overload. There is limited guidance on the practical implementation of flywheel eccentric training in the current literature. In this article, we provide literature to support the use of flywheel eccentric training and present practical guidelines to develop exercises that allow eccentric overload.

INTRODUCTION

Resistance training has been shown to play an important role in the enhancement of sports performance. Indeed, different reviews and meta-analyses have shown that muscular strength can improve various general sports skills such as jumping, sprinting, and change of direction (COD) as well as reduce injury risk (3, 99, 101, 106). Within the multiple training methods utilized to enhance strength, eccentric training has gained a special interest in recent years (46). Eccentric contraction corresponds to the active lengthening phase of muscle action. During this eccentric contraction, the muscle absorbs energy that is created by the external load (1).

Although the specific neural strategies during eccentric contractions are not fully understood, adjustments at both spinal and supraspinal level assist in particular modulation of voluntary activation during eccentric contractions (28). Eccentric strength has been shown to be ~40% greater than concentric strength in males and females and shown to be higher at faster movement speeds (77). Eccentric exercise is less metabolically demanding and requires less motor unit recruitment compared to concentric exercise for the same mechanical output (81, 82). This reduced motor unit activation has implications on eccentric coordination, with reduced fine motor control, as fewer motor units are needed for the same work (47). In contrast to the force-velocity curve during concentric contractions, force during eccentric contractions increases with higher speeds up to a point where it plateaus or slightly decreases (85). Higher speeds would also produce higher mechanical stress to active fibers (20), with some studies suggesting that high-velocity eccentric contractions do not follow the size-based order of motor unit recruitment (48, 71). In addition, following eccentric contraction there is residual force enhancement, which refers to an increase in steady-state isometric force after the lengthening action when compared to isometric force not preceded by an eccentric contraction (45), which could be related to the passive action of a structural protein, titin, interacting with actin and myosin (44).

ECCENTRIC TRAINING: MUSCLE DAMAGE AND DELAYED ONSET MUSCLE SORENESS

Due to the lower number of motor units being recruited during active stretch for a given load compared to concentric contractions, there will be greater force per motor unit activated, which could then cause exercise-induced muscle damage (49, 74). In any respect, recent research has shown that muscle damage would not come exclusively from eccentric exercise per se, as unaccustomedness to high-intensity eccentric exercise would also play an important role (55). It is essential to consider that muscle damage has been shown to be superior with greater loads (76), higher velocities (20, 116), long muscle lengths (86) and in inexperienced individuals (75), with genetic factors also playing an important part (7). The initial events causing muscle damage after eccentric contraction have been related to damage to the excitation-contraction coupling system as well as disruption in the sarcomeres (87). This could lead to a decline in active tensions, a rise in passive tension, shift in optimum length for active tension, swelling, soreness and reduced proprioception (86, 87). To avoid delayed onset muscle soreness (DOMS), it is important to consider the role of the repeated bout effect. The repeated bout effect refers to the protection against DOMS and muscle damage produced by a single bout of eccentric exercise on the successive eccentric bout which is thought to be related to neural, mechanical and cellular adaptations (65). Therefore, understanding how repeated bout effect attenuates the impact of DOMS and muscle damage can aid the progression and optimization of strength and conditioning programs. For example, although eccentric training at longer lengths has shown greater adaptations vs shorter lengths

(37), eccentric training at longer lengths can also cause greater DOMS. Adequate progression and overload would be suggested to reduce the negative impact of muscle damage.

TRAINING ADAPTATIONS AFTER ECCENTRIC TRAINING

These unique characteristics of eccentric contraction would lead to distinctive adaptations when compared to isometric or concentric. Indeed, eccentric, when compared to concentric training has shown increased gains in muscle strength, hypertrophy, and neural adaptations (91, 92). As higher weights can be lifted during eccentric training, it's not surprising that this training methodology shows higher increases in total strength when compared to concentric training (92, 96). Eccentric compared to concentric training could cause unique muscle and/or hypertrophy adaptations such as increased fascicle length, enhanced distal region cross-sectional area, lower pennation angle, increased number of sarcomeres, and enhanced muscle stiffness (16, 29, 31). The unique muscular and neural adaptations could explain the beneficial effects on performance as well as injury prevention in sports. Indeed, numerous studies have shown that eccentric training can reduce the risk of injury as well as the incidence and severity of an injury, being more successful than other training modalities or therapy interventions (51). Eccentric training has also been shown to elicit improvements in physical performance. For example, a metanalysis showed increased speed performance after eccentric biased hamstring strength (8) which could be related to higher hypertrophy of fast twitch fibers (32) and an increase in fascicle length (117). Other studies have shown an increase in power and stretch-shortening cycle performance to a bigger extent when performing eccentric compared to concentric training (29, 36, 52). In addition, different studies have shown higher improvements in COD performance after eccentric-biased training compared to conventional training (e.g. free weights) (21, 57, 114), which could be related to eccentric strength facilitating quick deceleration during COD actions (18).

STRENGTH IS SPECIFIC

As demonstrated by different studies, eccentric training would generate specific muscular and neural adaptations relevant to this type of training in comparison to other modalities (e.g., concentric and isometric training). In this sense, different studies have shown the specificity of strength training, where the type of training performed elicits larger improvements in specific tests vs non-specific tests (103). Therefore, when programming strength and conditioning programs for athletes, the characteristics of the sport should be considered. In this sense, different team sports (soccer, handball, Australian football, hockey, rugby league, rugby sevens, rugby union, basketball) have not only shown to have a significant amount of high and very high-intensity decelerations but also a higher frequency when compared to accelerations (40, 54, 119). In any respect, not every team sport shows this tendency. For example, American football players have been shown to perform a greater amount of high-intensity accelerations while lacrosse shows similar frequencies (43, 124). Furthermore, individual sports such as tennis or squash also require multiple decelerations and CODs (34, 121). This would be highly relevant, as severe decelerations would demand intense eccentric contractions (41, 42). Therefore, neuromuscular fatigue has been associated with the number of hard CODs during a soccer match (72). Sprinting generates large eccentric contractions (97) and has been shown to be related to muscle damage after a match in different team sports (33, 38). In this sense, strength training could reduce the impact of neuromuscular fatigue, as a recent study has shown that higher maximal strength performance, measured through an isometric test, allows players to recover quicker (2, 112). While no studies have analyzed how maximal eccentric strength would impact post-match fatigue and recovery, taking into consideration the factors associated with muscle damage and fatigue after a game, it would be suggested that a greater ability to absorb forces would have an impact on facilitating recovery, but further research is needed.

Interestingly, the only study analyzing the effects on accelerations and decelerations of an eccentric overload training protocol found improvements in variables related to the intensity of the accelerations and decelerations performed during a match (73). This has even greater relevance when taking into consideration that linear actions and decelerations show to be key movements in goal scoring situations (61, 62). Consequently, if we aim to enhance performance, improve recovery and decrease injuries in sports where decelerations, CODs and sprints are predominant, it would be suggested to take special consideration to eccentric overload training (19).

ECCENTRIC TRAINING MODALITIES: FLYWHEEL ECCENTRIC TRAINING

Different eccentric resistance training modalities exist within the literature such as tempo training (98), accentuated eccentric loading (122), eccentric cycling (6), plyometric accentuated eccentric loading (39), horizontal deceleration (50), change of direction training (26), downhill running (14), weightlifting derivatives (105) and flywheel eccentric training (12). Within these methodologies, flywheel eccentric training has gained popularity in recent years. This device consists of one or several flywheels attached to a rotating shaft (83) (Figure 1). The flywheel device allows for mechanical eccentric overload by returning inertia accumulated by the rotating wheel during the prior concentric phase (9). The movement starts until the rope is completely unrolled (concentric phase). The device then continues rotating due to inertia, making the rope recoil. The kinetic energy from the concentric phase is then transferred to the eccentric phase and an equal impulse is needed to stop the rotation of the disc (95).

Flywheel eccentric training has several advantages that make it an attractive option. 1. It allows not only a wide variety of exercises but also sport specific movements in all three planes with similar kinematics to the sport (84). 2. Accommodated resistance where effort is maximal from the first repetition (111). 3. Maximal force in every angle without a 'sticking point' (118). 4. Accommodated resistance allows for continuous change in movement during each repetition or each of the phases of the set (113). 5. Portability of the device, which can easily be moved and used at different venues (109).

Different types of flywheel systems exist (Figure 1): horizontal cylinder shape (flywheel squat, flywheel leg curl, flywheel leg extension, flywheel leg press, flywheel pulley, flywheel multi gym) and vertical cone. This vertical cone, also known as the 'conical pulley', has an increasing radius from the top to the bottom (22, 69). It has been shown that while a horizontal cylinder-shaped device would allow for higher forces during the eccentric phase, vertical cone shaped devices can achieve higher speeds (69).

When performing flywheel eccentric training, the nomenclature utilised for different loading intensities would differ from that utilised in traditional strength training. Low/high inertia during flywheel training would equate to light/heavy load in traditional strength training. Depending on the inertia of the disc or cone the exercise prescribed will potentially target different parts of the force-velocity curve (low inertias stimulating rightward shift and high inertias upwards shift of force-velocity curve) (64). Testing performed on flywheel devices have shown to be reliable in different spectrums of the force velocity curve in male sport athletes and physically active male and female (11, 104). While training loads can be modified by increasing speed or adding flywheel weights, the efficacy of this training method to apply eccentric overload is the intention to apply force at the maximum speed possible during the concentric phase and stop the rotating movement during the eccentric phase (10, 59, 109). Eccentric actions are hardly ever performed in isolation during real-life circumstances but will commonly occur during the stretch-shortening cycle (eccentric, amortization, concentric) (58). It has been consistently demonstrated that compared to non-stretched muscle, pre-stretch during eccentric muscle contractions can produce greater force and power output during successive concentric contraction (Bosco, 1997). In this sense, flywheel eccentric training is based on stretch-shortening cycle with greater overload than other gravity-dependent exercises (i.e. countermovement jump) (70), with recent research showing higher forces during coupled eccentric-concentric compared to isolated concentric muscle action (60), More so, the level of inertia will have an impact on the degree of stretch-shortening cycle utilization, which is maximized when using low to medium inertias (60).

Figure 1 here

Figure 1. Different types of flywheel systems. Device generic name – device name from the commercial company (photo). Flywheel squat - Desmotec D.Evo (A); flywheel multi gym - Acceleration Multi Gym (B); Acceleration Leg curl (C); flywheel pulley - Desmotec V.Full (D); conical pulley – Acceleration Pulley Fast (E); flywheel leg extensions - Acceleration Leg Extension (F); flywheel leg press - #212 YoYo Leg Press (G).

TRAINING EFFECTS AFTER FLYWHEEL ECCENTRIC TRAINING

Physical performance

While general benefits of applying eccentric training have been described previously in this article, flywheel eccentric training has shown multiple benefits for the enhancement of different physical capacities in athletes. Due to the recent popularity of this training method, several meta-analysis and narrative reviews have analyzed the ability of flywheel training to enhance different physical capacities such as strength, power, speed, and COD in athletes. An important number of meta-analysis and narrative reviews support the ability of flywheel training to enhance strength and power and/or jump variables when compared to control or traditional training (4, 58, 90, 95) while Vicens-Bordas et al. (120) found no differences between flywheel eccentric training and gravity-dependent resistance training. Interestingly, Petre et al. (83) found higher improvements among younger individuals as well as well-trained athletes, which was hypothesized to be related to experience athletes being more active in the concentric and eccentric phases. Improvements in power and/or jump variables during flywheel eccentric training have been theorized to be related to the eccentric overload stimulus which could produce improvements in stretch shortening-cycle and stiffness as well as improvements in movements pattern linked to successive improvements in concentric action (90). As mentioned, increases in strength after flywheel eccentric training could be related to the potential eccentric overload produced, especially when an increase in force is significantly higher after flywheel eccentric training with the presence of overload (95).

Different meta-analyses have also shown the ability of flywheel eccentric training to increase sprint performance (58, 83, 90). Several authors highlight the fact that improvements have been achieved with different types of flywheel eccentric exercises (i.e., squat, leg curl, leg press and multi gym) (25, 90). Improvements in sprinting ability through flywheel eccentric training could be potentially related to eccentric overload training possibly causing shifts toward-faster muscle phenotype (32). The ability of flywheel eccentric training to enhance COD performance has also been examined in different meta-analyses (4, 18, 53, 90). Within these meta-analyses, it is important to consider that Raya-González et al. (90) only included flywheel eccentric training, with Liu et al. (53) incorporating 8 out of 11 studies performed with flywheel devices, while Allen et al. (4) only included soccer players. These meta-analyses found flywheel eccentric training to be a superior method to enhance COD performance vs the control and/or traditional resistance training groups. While unique adaptations after eccentric overload training could justify these findings, other characteristics could also explain these encouraging findings. For example, flywheel eccentric training facilitates specific strength training in multiple planes (35) and enables sport-specific movements to be optimized (84). Modifications in kinematics variables after flywheel eccentric training could also play an important role (53), as faster COD performance is related to shorter ground contact times and greater braking and propulsive forces and impulses (27, 102). In this sense, de Hoyo et al. (24) found significantly lower braking and propulsive contact time as well as greater braking and propulsive forces and impulses during a COD test after flywheel eccentric training in U19 soccer players. In this study, the experimental group performed flywheel eccentric training (half squat in flywheel squat and leg curls in flywheel leg curl) utilizing inertia that achieved the highest power output 1 or 2 times/ week for 10 weeks, while the control group did not perform any type of resistance training during this period. While this research represents steps in the right direction, researchers should aim to examine the effectiveness of flywheel eccentric training in specific team sport environments. For example, a recent study by Nevado-Garrosa et al. (73) analyzed the impact of eccentric overload training through flywheel eccentric training or small-sided games (SSG) vs a control group on acceleration and deceleration variables during a soccer match in female under 23 players. Players performed 10 sessions of eccentric overload training using flywheel devices. Subjects performed 5 lower body exercises starting with 1 set of 6 repetitions and ending with 2 sets of 7 repetitions. The exercises performed were squat and lateral squat, lying glute kickback, split, and two-leg curl using different flywheel devices. While the SSG group showed improvements in variables related to effort repetition and the ability to maintain accelerations and decelerations over time, the eccentric overload group showed improvements in the distance travelled accelerating and decelerating at high intensity, maximum acceleration and deceleration and average acceleration and deceleration compared to the control group (73). While this pioneering study supports benefits found in controlled environments, more research is needed to gain a better understanding on how flywheel eccentric training can affect match performance as well as recovery after individual and team sport events.

Injury Prevention

Flywheel eccentric training has been shown to promote positive adaptations to protect athletes from muscle and joint injuries (67) as well as being an effective training method for the treatment of tendinopathies (15). Studies performed in team sport athletes have shown flywheel eccentric training to be effective in reducing the number of injuries in a season (5, 23), which could be related to the specific neuromuscular adaptations such as increased muscle fascicle length (5, 78). In any respect, these studies compared flywheel eccentric training with a control group. More research is needed to understand the effectiveness of this training method vs other resistance training methods.

IMPLEMENTATION OF FLYWHEEL ECCENTRIC TRAINING

While in recent years there has been an increased interest and an exponential number of studies on flywheel eccentric training, this method is novel compared to other training methods such as traditional resistance or power training. Therefore, it’s not surprising that different authors have highlighted the lack of guidance or practical implementation within a training program, hence, being difficult to substantiate the use of flywheel eccentric training interventions (80). Several authors have suggested suitable guidelines based on the available research. Researchers recommend 2-3 exercises, from 1 to 6 sets of 6 to 8 repetitions with

1’30’’ to more than 3’ of rest between sets (10, 12, 88, 110, 111). In this regard, the inertia utilized would dictate the amount of rest time needed, with higher inertias requiring more rest time (93). It is also important to consider that 1 to 4 repetitions are required to accelerate the flywheel (56, 94).

Regarding the intensity of training, researchers have recommended the use of high inertias for strength adaptations (i.e., >0.050 kg·m^2) and low inertias for power adaptations (i.e., 0.025–0.050 kg·m^2) (12). In relation to the training frequency, authors have recommended 1 to 3 sessions/week with 48 hours of recovery between sessions (10, 88, 110, 111). This would depend on the phase of the season, with researchers recommending 2 sessions during the off-season and a minimum of a single dose during the in-season (12, 88). Finally, when looking at exercise selection, multi-joint exercises are recommended to enhance strength and power, which would potentially transfer to sports performance, while single-joint exercises may be more beneficial when the objective is to prevent injuries (12). Raya-González et al. (88) proposed low to high inertias for performance enhancement and high inertias for injury prevention. These recommendations are typically based on the available experimental research, which is limited compared to traditional strength training, and should be taken with caution. When providing training recommendations for the enhancement of different physical capacities through flywheel eccentric training we should take into consideration both available literature on flywheel eccentric training and other eccentric overload training recommendations (e.g., accentuated eccentric loading, tempo training, etc), as well as the wide body of evidence available on traditional strength and power training. Table 1 provides guidelines for power, strength, and injury prevention training with flywheel devices. This table presents general recommendations that can be specified depending on the periodization stage. Specific guidance based on the season phase is beyond the scope of this paper.

Table 1 here

WEEK ORGANIZATION

When looking at weekly organisation, Beato et al. (12) have recently proposed a specific week periodisation that includes flywheel eccentric training. The authors include 3 different scenarios, off-season, in-season, and 2 game/ week. During off-season and in-season they propose 2 to 3 flywheel eccentric training sessions. During the off-season, the first flywheel eccentric training session would be performed in the morning of match day minus 4 (MD-4) which would have a strength and injury prevention focus, while on match day minus 2 (MD-2) these authors recommend a power session, before the training session. During in-season, Beato et al. (12) propose non-starter to perform a strength/IP session on match day plus 2 (MD+2), a strength and injury prevention session, and a power session for starters and non-starters, respectively, on MD-4, with a power session for both starters and non-starters being performed on MD-2. In Table 2 we propose an alternative schedule for team sports that can be performed during both pre-season and in-season. Non-starters would perform a strength/IP session (including flywheel eccentric training) after the match. Both starters and non-starters would then perform a power session (including flywheel eccentric training) on MD-4. The benefits of performing a power session on MD-4 before training would be related to players having around 72 hours of rest post-match (with potentially some type of light training on MD+2), and would perform this power session with absence of fatigue. Performing this power session before the training practice would potentially have a post-activation potentiation effect (13). In Table 2 we propose an upper body session after training on MD-4, as well as a strength and injury prevention microdosing session (1-4 exercises including 1-2 exercises flywheel exercises, 1-2 sets) which potentially would not cause any major fatigue and would provide a small strength stimulus. Subsequently, on match day minus 3 (MD-3) after training, athletes would have their main strength and injury prevention session.

On the other hand, on a 2 game/week, Beato et al. (12) propose a flywheel power session on the MD+2/MD-2 of the first match and match day plus 1 (MD+1)/MD-2 of the second match. We propose that non-starters perform a strength and injury prevention session post-match on the mid-week game and a power session on the MD-2 of the 2nd game (Table 3). On the other hand, starters would perform a strength and injury prevention microdose stimulus after the midweek game. This would mean that athletes get a strength stimulus, which could marginally increase fatigue and/or muscle soreness markers, but in favor, would not be exposed to any other potentially muscle damaging stimulus over MD-2 and match day minus 1 (MD-1), where recovery strategies would be prioritised. While it could be argued that this strength stimulus could mean a risk for the athlete, teams playing consistently 2 matches each week would have a very limited window for strength training, which if ruled out, would outweigh the risk of performing this. When utilizing this strategy, it would be recommended to perform exercises that players are used to, in order to benefit from the advantages of the repeated bout effect and avoid additional DOMS. While Table 2 and Table 3, only specify strength, injury prevention, and power objectives, exercises and movements that are specific to COD enhancement or speed can be also added. In this sense, as part of the strength protocol we would include COD-focused exercises using flywheel eccentric training while during the power session, speed exercises would be recommended.

Table 2 here

Table 3 here

CAN FLYWHEEL TRAINING CREATE ECCENTRIC OVERLOAD?

During conventional resistance training involving concentric, isometric, and eccentric contractions the same absolute load is applied in all three phases, which infers a lower relative eccentric load. Therefore, when isolating the eccentric phase with the same absolute load, this would be substantially underloaded. On the other hand, applying eccentric overload would impose a higher load compared to what the subject would lift during the concentric phase (32). This difference is of major importance, as the ability to create eccentric overload during flywheel eccentric training shows significantly higher increases in force compared to flywheel eccentric training with no overload (95).

Although It has been suggested, based on the research population performing flywheel eccentric training, that this type of eccentric overload exercise would be more suitable for untrained individuals and/or during the offseason (110), recent research has highlighted the superiority of flywheel eccentric training in well-trained athletes (83) while other authors support the use of flywheel eccentric training during the in-season (12).

It has been debated whether flywheel devices can create eccentric overload, or if, the eccentric stimulus is only equivalent to the energy created in the concentric phase (109). A recent meta-analysis showed that only 17 out of the 79 studies that used a flywheel device provided enough data to ascertain the presence of eccentric overload (68). In these studies, the metrics showing evidence of this eccentric overload were peak power and peak velocity (68). One explanation for the lack of eccentric overload produced in these studies could be related to the kinetics and kinematics of the movement performed. For example, during a squat in a flywheel squat machine maximal concentric forces are generated when knees and hips are relatively extended where mechanics are advantageous, while peak eccentric forces are produced in an unfavourable mechanical position where knees and hips are extended near the turning point (100). In addition, the timing of the forces created by different muscle groups combined during a squat (multiple muscle groups are being contracted) differ throughout the course of a certain cycle during eccentric and concentric contractions (100). Another reason for the lack of eccentric overload is related to the concentric phase not being performed at maximum intensity, which means that the eccentric phase requires less than maximal effort. For example, if a novel athlete is performing a leg extension in a flywheel leg extension device with a low concentric speed due to inexperience or lack of understanding, throughout the eccentric phase the kinetic energy that the athlete absorbs would not be enough to generate eccentric overload. In order to create eccentric overload authors recommend modifying the tempo and range of motion during the eccentric phase (i.e. decelerating or slowing down at the end of the eccentric phase) (70). Horizontal cylinders and higher inertias have shown more likelihood of creating eccentric overload (60, 69). Finally, experience and gender could also influence creating (or not) eccentric overload (60, 115).

IMPORTANT CONSIDERATIONS WHEN ADDING FLYWHEEL EXERCISES

Flywheel eccentric training as part of a holistic strength and conditioning program

When flywheel eccentric training is prescribed, it is important to conjugate this as part of the whole program and not solely add more exercises to the ‘mix’ without an underlying justification. For example, if we identify the need of an athlete to perform squats with free weights within their program, although this exercise holds some biomechanical and neuromuscular differences to performing a squat in a flywheel device (17, 63), these are very similar exercises. Generally, it would make sense to perform alternative flywheel exercises based on the athlete’s needs. Table 4, Table 5, and Table 6 provide examples of how flywheel exercises can be incorporated into a training program.

Number of exercises

The number of flywheel exercises within the program is also something that needs special consideration. For an athlete with low experience in flywheel eccentric training, 1-2 exercises and sets per session can be more than enough to start, while athletes with high expertise would be able to tolerate a higher volume (e.g., 2-4 exercises, 2-4 sets). Indeed, due to the potential muscle damage caused by eccentric exercises, we need to consider the volume, intensity, and progression of exercises as well as the timing of the sessions to avoid excessive DOMS that can affect other key team or individual training sessions. When increasing the eccentric overload, especially when prescribing exercises with high inertia and high overload, we need to consider appropriate timing, particularly in team sport contexts where matches are programmed almost every week if not 2 times/week. A lower training load week, international break week (for non-international players), longer week between matches (+ 7 days between matches) or compensatory sessions (non-starters, card suspensions, etc) could be ideal scenarios to make modifications and increase the eccentric overload.

Adequate technique before progress

Something of particular importance is the assurance that these exercises are performed with correct technique to avoid any potential injury or compensation that can lead to injury. This would be critical as the athlete would be exposed to a supra-maximal load. Therefore, when starting to use these devices and progressing to higher overload or a more challenging exercise, we need to be assured that the athlete can tolerate this load with adequate technique. In this sense, while the present literature does not offer any recommendations on the suitable age to start utilizing flywheel devices, different studies have performed experimental research with athletes up to 13 (30). Other parameters such as technique or training experience would be more important on the decision-making process.

Safety

When performing flywheel exercises, especially during high eccentric overload, we need to ensure that the athlete has a way to stop safely during the eccentric phase in case of failure. This might not be necessary for certain devices, such as flywheel leg curl, flywheel leg extension, flywheel leg press, flywheel pulley, flywheel multi gym or conical pulley, as inertia can be stopped differently, but would be essential when performing exercises on the flywheel squat device. Some flywheel squat devices incorporate a bar to hold on to in case the athlete needs to hold on to it (i.e., if the athlete can not cope with the kinetic energy produced in the eccentric phase). Another important consideration would relate to the adequate adjustment and connection of the harness to the flywheel device. The harness should be worn around the shoulders (unless using a hip harness), with safety clips around the chest appropriately attached. Before performing the exercise, the athlete should position himself static on final the position of the concentric phase of the exercise about to be performed (i.e., on the squat, with extended knees and hips), to adjust the length of the rope so that there is no lag or delay when transitioning from the concentric to the eccentric phase.

Common technical errors

During exercises where the concentric phase ends on hip and knee extensions, it is important to instruct the athlete to start bending knees and hips immediately after the concentric phase ends, as inexperienced athletes tend to maintain an extended locked position, which leading to great risk to the athlete. When performing exercises on the flywheel squat, forward and/or backward lean could lead to losing balance and injury to the athlete. In addition, coaches should ensure that the athlete places their feet in the middle of the platform and not in the front or back edges to avoid any movements, especially on lightweight flywheel squat devices. Finally, athletes should be educated in using the ‘stop’ placed on the device to finish the exercise safely.

Adding plantar flexion for a smooth transition

While ankle plantar flexion would be per se one of the recommended methods to overload the eccentric phase, a certain amount of plantar flexion would be recommended in most exercises where full hip and knee extension is required, as this would allow the athlete time to transit from the concentric to the eccentric phase. For example, if a squat is performed in a flywheel squat machine and the athlete reaches full knee and hip extension when the rope/cord comes to the end of its full length (at the end of the concentric phase), this would have minimal time to start the eccentric phase before getting ‘stuck’ on a hip and knee extended position. If this occurs, a large amount of kinetic energy (if not all) would be absorbed in the beginning of the eccentric phase, where there is a mechanical advantage.

Specificity

As mentioned earlier, one of the advantages of flywheel eccentric training is the ability to perform a wide variety of exercises in all three planes with similar kinematics to the sport (84). To use this to our advantage, when creating strength and conditioning programs, we will need to take into consideration the physical characteristics we are aiming to improve and how can this be targeted. For example, if we are looking to improve the horizontal deceleration ability of a player, it would make sense to prescribe strength exercises performed in the sagittal plane (i.e. a forward lunge using a conical pulley/ flywheel pulley or flywheel squat) (Figure 2) where during the concentric phase kinetic energy is created on a posterior direction and throughout the eccentric phase we absorb the kinetic energy on an anterior direction. On the other hand, to improve jump capacity, we would perform the squat in a flywheel squat with plantar flexion and perform this either double leg or single leg utilizing low inertia (Figure 4, photosequence 1). In this sense, performing this exercise with plantar flexion would not only allow eccentric overload but would also make it a ballistic exercise which has shown potential benefits when compared to non-ballistic squats (107, 108).

Figure 2 here

Figure 2. Forward lunge in flywheel Squat

Direct feedback

We should consider direct feedback, as flywheels usually incorporate encoders and/or force plates (68). In this sense, th flywheel companies commonly provide an app that allows live feedback showing metrics such as peak or average power and/ or force during concentric and eccentric phases. This would allow to: 1. Make the athlete aware of the power and/or force exerted and comprehend if eccentric overload is generated during each repetition to make slight technique modifications if needed. 2. Follow week-to-week variations. 3. Acknowledge the applied overload when performing new exercises and understand if there are substantial increases. 4. Motivate the athlete by receiving direct feedback (123).

METHODS TO CREATE ECCENTRIC OVERLOAD WHEN USING FLYWHEEL DEVICES

Different methods can be utilized to facilitate eccentric overload during flywheel eccentric training. Each method would be suitable for determined types of flywheels and could potentially generate different levels of overload (Figure 3). Figure 4 shows the photo sequences of each of the method proposed to create an eccentric overload with a flywheel squat device as an example. Photographs show the start of the concentric phase, end of the concentric phase, start of the eccentric phase and end of the eccentric phase.

Figure 3 here

Figure 3. Methods to create eccentric overload when using flywheel devices.

Increased range of motion on the concentric phase

Adding plantar flexion (beginner)

When adding plantar flexion (i.e. to a squat movement) we are adding range of motion to the concentric phase which we then would not absorb in the eccentric phase as there would not be necessarily an eccentric plantar flexion phase (the athlete would go straight into the eccentric phase of a squat). There would be more kinetic energy to absorb in less time during the eccentric phase. More so, we are adding the force output of muscles on the concentric phase that would not be involved in the eccentric phase, such as the plantar flexors. The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video ‘Adding plantar flexion’.

Adding Hip Rotation (intermediate)

Similar to adding plantar flexion, by adding hip rotation on the last 3d of the concentric phase we are increasing the range of motion as well as the involvement of specific hip rotator muscles in this phase, which we will then reduce its involvement during the eccentric phase. For example, when performing a squat with rotation, the concentric range of motion would increase, and the amount of kinetic energy produced would also increase. During the eccentric phase, the athlete would naturally avoid absorbing the kinetic energy generated at the beginning of this phase, when he/she is still rotating back to the natural standing squat position, and would slightly delay the force absorption to when he/she is in a more leveled or symmetrical position after the initial rotation (i.e. after the first 3d of the eccentric phase). The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video ‘adding hip rotation’.

Reduced range of motion on the eccentric phase

Alternated ranges of motion (beginner)

This modality would consist in performing the same exercise with a different range of motion on each repetition. For example, performing a ½ squat followed by ¼ squat. In this case, all the kinetic energy generated during the concentric phase of the ½ squat then needs to be absorbed in a reduced amount of range during the ¼ squat, creating eccentric overload. The drawback of this method is that in the next phase of the exercise, during the ¼ squat, there is less time to generate the force, which is then absorbed in a ½ squat. As the athlete can ‘play’ with the range of motion and alternate phases where there is eccentric overload with others where there is not, this can serve as an introduction to an eccentric overload program. The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video ‘alternated range of motion’.

Stopping inertia during the last 3d of the Eccentric phase (intermediate)

In this case, all the kinetic energy generated during the concentric phase would need to be absorbed through a shorter range of motion. While stopping the inertia in the last 3d of the motion is the most common method utilized in literature to generate eccentric overload on a flywheel device (68, 89), athletes can also be asked to stop the inertia at a different point (i.e., halfway through the downward phase, first 3d of the movement). The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video 'stop inertia in the last 3d'.

Catch (advanced)

In this case, the athlete will perform the concentric phase and then try to absorb the forces close to the bottom position. All the force accumulated in the concentric phase would have to be absorbed isometrically in a very short amount of time. In almost every case, the athlete would be unable to hold that position, with the kinetic energy pushing the athlete further down, creating an eccentric contraction. This would involve a failed isometric action and a subsequent eccentric contraction, termed in the literature as an eccentric quasi-isometric contraction (79). The main difference is that the literature has explained this term as the transition from an isometric to an eccentric contraction which comes from the fatigue developed by maximally resisting an isometric contraction for as long as possible until fatigue causes muscle lengthening (79). Instead, during a 'catch' on the eccentric phase of flywheel exercises, the eccentric action would not come from the fatigue caused by continued isometric contraction but from the inability of the muscles to absorb all the kinetic energy created on the concentric phase during the 'catch' or isometric contraction, and the remaining kinetic energy is absorbed through an eccentric contraction. This would be one of the exercises that reach the highest eccentric overload within the methods described. The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video 'catch'.

Coach/athlete/load assisted overload

Assisted concentric (intermediate)

This would involve the athlete itself or a coach/ trainer assisting in the concentric phase of the movement and allowing the athlete to complete the movement unassisted during the eccentric phase. In this sense, a recent study found greater concentric outputs which induced greater eccentric outputs when performing assisted squats in a flywheel squat device (125). Indeed, when performing an assisted concentric phase, the athlete is generating more kinetic energy during the concentric phase compared to what this would be able to produce on his own, having to absorb that extra kinetic energy during the downward phase. For example, when performing a squat on a flywheel squat machine, the athlete would assist the concentric phase by holding and pushing with the hands from an immobile device (i.e. barbell, rack, etc) and on the way down would free up the hands so that she/he must absorb not only the kinetic energy generated by the lower limb but also the kinetic energy generated by the upper body. If the coach is performing the assistance, this would pull the rope up on the concentric phase and then release it on the eccentric phase. This would be more challenging for the athlete as he/she is not in control of the extra kinetic energy generated. The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video 'assisted concentric'.

Assisted eccentric (advanced)

Contrary to the concentric assisted, in this case, the athlete would perform the concentric phase unassisted, and during the eccentric phase the coach/trainer would assist by pulling down the rope/cord. This would mean that the athlete needs to absorb more kinetic energy vs what he/she had created previously during the concentric phase. Compared to other methods the athlete would not have control of the eccentric phase per se, as the energy absorbed would be dependent on the speed at which the coach/trainer pulls the rope/cord. This method requires experienced athletes and coaches to be performed safely. An alternative method would involve the athlete pushing himself/herself down applying force on an external object (e.g. rack or barbell placed on the rack). Again, the level of difficulty would be pronounced, as the athlete is trying to decelerate with the lower limb/s the inertia from the flywheel simultaneously pushing itself down, which can be highly difficult to coordinate for athletes with low experience on flywheel eccentric training. The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video ‘assisted concentric’.

Additional load/weight on the eccentric phase (intermediate)

This modality would have similar principles to that of accentuated eccentric loading or plyometric accentuated eccentric loading where the load lifted during the eccentric phase is higher compared to the load lifted in the concentric phase. Due to the nature of flywheel eccentric training, where the athlete is attached to a harness and performs continuous concentric and eccentric movements on the same set without a pause, the characteristics of the extra load added would differ from accentuated eccentric loading or plyometric accentuated eccentric loading. The added load would need to be comfortable and fast to release from the athlete at the end of the eccentric phase and for the coach to hand back to the athlete at the end of the concentric phase/ beginning of the eccentric phase (e.g., medicine ball, kettlebell, etc). For example, the coach would pass a medicine ball at the end of the concentric phase to the athlete, who would have to carry the added load through the eccentric phase, creating the eccentric overload. When the eccentric phase ends, the athlete would give the medicine ball back to the coach. The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video 'Additional load/weight on the eccentric phase'.

Alternation of exercises/laterality between phases

Change in exercise between phases (advanced)

The concatenation of exercises within the same set during flywheel eccentric training has been described by Tous (2017). This method is because certain exercises would generate more kinetic energy during the concentric phase than others. If the exercise generating higher kinetic energy is switched to a different exercise during the eccentric phase, this will potentially generate eccentric overload. In any respect, eccentric overload would only be generated if the exercise performed during the concentric phase can be completed at a higher speed and/or with an increased range of motion (with higher kinetic energy generated) compared to the exercises performed during the eccentric phase. For example, when performing a squat on the concentric phase, followed by an RDL on the eccentric phase on a flywheel squat device. As during the concentric phase of the squat the athlete would generate higher speeds compared to what would be generated on the concentric phase of an RDL, the athlete would need to absorb the kinetic energy produced on the concentric phase of the squat during the eccentric phase of the RDL. The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video 'Change in exercise between phases'.

Bilateral to Unilateral change between phases (advanced)

This method has been previously proposed for both flywheel (68) and free weight exercises (66) and would involve a concentric phase performed with 2 limbs and an eccentric phase with 1 limb. When performing this exercise on a flywheel device, all the kinetic energy generated with 2 limbs would be absorbed by 1 limb on the downward phase. Due to its nature, in certain exercises, an element of support (such as a barbell placed in the rack to hold on to) is required. For example, when performing a bilateral squat on the concentric phase and a unilateral squat on the eccentric phase (on a flywheel squat machine). When the athlete transitions to a single limb in the eccentric phase, the kinetic energy would be pushing the athlete diagonally down toward the middle of the flywheel (as the rope would be recoiling). The athlete must balance by holding a barbell, rack, etc. This means that some amount of kinetic energy is absorbed by the arms. These exercises would produce one of the highest eccentric overloads within the methods explained. The different phases of this method are depicted in Figure 4 and the full exercise can be seen in the supplementary video 'Bilateral to Unilateral change between phases'.

Combination of methods (advanced)

This method would include combinations of the proposed methods to create eccentric overload. Only elite athletes with high expertise would be able to tolerate the overload and complexity of these. The combinations can be endless. For example, adding rotation to a squat on the concentric phase and decelerating on the last 3d of the eccentric phase. In this example, we would increase the time producing kinetic energy during the concentric phase by adding a rotation element and then reduce the time to absorb the kinetic energy generated by stopping on the last 3d of the movement. Another example could be to assist the athlete during the eccentric phase and 'catch' the device during the eccentric phase. In this case, the additional kinetic energy generated during the concentric phase by assisting the athlete would need to be absorbed during the catch phase.

Figure 4 here

Figure 4. Photosequence of the different methods to create eccentric overload. (1) adding plantar flexion; (2) adding hip rotation; (3) alternate range of motion, (4) stop inertia on last 3d; (5) catch; (6) assisted concentric; (7) assisted eccentric; (8) additional load on the eccentric phase; (9) change in exercise between phases; (10) bilateral to unilateral change between phases; (A) start of the concentric phase; (B) end of the concentric phase; (C) start of the eccentric phase; (D) end of the eccentric phase

Table 4 here

Table 5 here

Table 6 here

PRACTICAL APPLICATIONS

Different types of flywheel systems are available in the market, which when used appropriately can effectively provide eccentric overload. When using flywheel devices, eccentric overload should not be taken for granted (68). While the achievement or not of eccentric overload could be somehow explained by certain kinetic and kinematic reasons (60, 100), as well as the characteristics of the athletes performing the exercises (60, 115), special attention should be placed on the exercise selection, as this can determine the level of overload achieved. The different methods that can be performed to create eccentric overload go from increasing the duration of the concentric phase, reducing the duration of the eccentric phase, assisting the overload on both concentric and eccentric phases, and alternating exercises between phases. Practitioners can combine different methods to further progress the level of overload and complexity of the exercises.

Practitioners should have a clear short-, mid- and long-term strategy based on the athlete’s level of expertise, considering their weekly schedule (Table 2 and Table 3). More so, flywheel eccentric training should be included as a conjugated part of the athlete’s program (Table 4, Table 5 and Table 6) considering their overall and specific objectives.

Video Abstract.MP4

Adding plantar flexion.MP4

Adding hip rotation.MP4

Alternated range of motion.MP4

Stop inertia on the last 3d.MP4

Catch.MP4

Assisted concentric.MP4

Assisted eccentric.MP4

Additional load on the eccentric phase.MP4

Change in exercise between phases.MP4

Bilateral to unilateral change between phases.MP4

ACKOWLEDGMENT

I would like to acknowledge Julio Tous-Fajardo, as he was the person introducing me to the flywheel training methodology and has been an important inspiration for this article.

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