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New Perspectives for the Resistance Training of Runners: Flywheel Approach

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ABSTRACT

Strengthening muscle is a critical aspect of injury resistance and training for performance gain, and as such, a wide variety of resistance training methods are available to the coach. Many of these training methods have been shown to enhance running performance, however, the influence of flywheel resistance training (FRT) is relatively unknown. FRT is known for a concentric force-time profile similar to ballistic movement and also for the eccentric overload the technology provides. Both these features could have positive adaptive effects for running performance. Initially some of the benefits of FRT as compared to traditional resistance training are discussed. With limited research in the area, what little is known is discussed and integrated into loading parameters and training guidelines for using this technology to improve running performance. Finally, some of the limitations and future research directions are detailed.

INTRODUCTION

Traditional types of resistance training and their application to performance enhancement for running is a well-documented area of research (7). For example, improvements have been documented using a wide variety of training methods such as plyometric (10, 16), traditional free weight training (14), and resisted sled training (23). A new modality of resistance training which is less documented in relation to its potential benefits in running performance is flywheel technology.

Flywheel resistance training (FRT) is a type of strength training that is gravity independent and involves an individual pulling a tether on a rotating shaft, which creates movement of a flywheel disc. The flywheel disc spins around an axis of rotation, creating angular momentum and/or energy during the pulling or concentric phase (22). This momentum is then stored and released during the eccentric phase (27). The magnitude of the resistance is created by the rotational inertia (I) of the flywheel, which is the product of the mass (m) and the radius of the flywheel (r) i.e. $I = m.r^2$, as well as the angular velocity of the flywheel. Larger flywheels have greater rotational inertia and therefore require greater forces to change their inertial resistance (22). When the tether attached to the axle reaches its full extension, the stored angular energy seeks to return to a state of rest as quickly as possible. This rapid retraction creates an eccentric overload by re-wrapping the tether around the rotational axis, thereby pulling the individual. FRT is well known for the eccentric overload it provides (21, 22), and some companies (Exerfly, WI, USA) have augmented the eccentric overload with motorised eccentric boost technology. This technology quantifies the instantaneous velocity towards the end of the concentric phase and depending on the user input can boost that concentric velocity by 1-80% at the beginning of the eccentric phase, thus producing a supramaximal eccentric overload. Furthermore, FRT enables the user to accelerate through most of the concentric phase, simulating ballistic force-time profiles similar to running and jumping without the impacts created from the airborne phase of such movements (27).

Considering the eccentric overload and the concentric force time profiles, it would seem that FRT could be a form of training that may produce benefits for running performance. Given the lack of knowledge around FRT, one aim of the article was to heighten the awareness of this form of training.

As such the focus is on FRT, however, the authors also acknowledge that the absence of reference to traditional reference training (TRT) does not underscore the importance of this type of training in the strength and conditioning of runners. With this in mind, the primary aim of this article is to discuss the unique benefits that FRT may provide for runners. Thereafter some of the research in the area is integrated into suggestions around loading parameters and training guidelines as to how running performance may be improved utilising flywheel technology.

Benefits of Flywheel Resistance Training

Because of the gravity independent nature of FRT there are a number of potential benefits different to TRT for runners, these benefits will be explored further in the ensuing section.

Portability

As a gravity independent device, FRT only requires a minimal number of light weight plates to create a significant resistive overload. This is a huge benefit in comparison to a traditional, gravity dependent strength training environment, where large numbers of heavy plates and numerous other pieces of equipment are needed to provide the required resistive overload. Flywheel technology, such as a platform, can be easily transported to locations to make training easier, more efficient and to enable combination training, which otherwise would not be feasible. For example, FRT can be used court, track or field side for top ups or to train and maintain in-season strength and power performance, where time for such training is often limited. Additionally, for game or race day, flywheel platforms or rack mounts can be a useful additional tool for athlete and team potentiation activities (6).

Autoregulation/Individualisation

Another potential benefit to FRT is that the resistive overload autoregulates to an athlete's current physiological status. That is, if an athlete is injured with limited range of motion and contractile force-velocity capability, then concentric contractions will be slow and weak, and therefore the angular momentum/kinetic energy (AKE) stored and returned in the eccentric phase will be minimal also, as the concentric and eccentric phase are directly proportional in reference to momentum and AKE. As an athlete returns from injury, their range of motion (ROM) and contractile force-velocity capability increases, which in turn will be matched by the resistive load that the flywheel produces on the eccentric phase as a direct result of increased momentum and AKE produced during concentric movement phases. An athlete's neuromuscular status at any given time defines the flywheel concentric velocity and therefore eccentric overload, resulting in a reduced likelihood of underloading or overloading the musculotendinous tissue. This concept is also important in terms of the individualisation principle due to the natural autoregulation the technology provides. As a result there is less likelihood of injury and greater likelihood of optimising athletic outcomes in terms of running performance.

Density/Efficiency/Specificity

One key advantage of FRT is that athletes can fit more into a training session, given that there is no rest between concentric and eccentric phases, as well as repetitions, compared to TRT. Therefore, athletes are able to overload their musculature consistently and more efficiently. Additionally, due to the nature of FRT and its ability to naturally autoregulate to the force capability of the user, athletes and coaches do not need to be constantly changing the plates on the flywheel. That is, once an individual becomes stronger, they can produce more force during the FRT, in turn, creating a greater eccentric force and load on the muscle (21, 22, 33). Finally, the continuous nature of FRT and the rhythm and flow of movements like squatting, more closely simulate running motion and therefore have greater movement specificity.

Injury/Safety

Because of the autoregulatory nature of FRT there is less likelihood of overloading the tissues in an injurious manner. Given the weight and utility of the plates, there is less need to be changing resistance and subsequently less likelihood of injury in regards to lifting plates or dumbbells. Furthermore, in many of the exercises, waist and shoulder harnesses are used, which means you can target train the legs more safely i.e., back strength is not a limiting factor. For example, if an athlete has a 100 kg barbell placed across the shoulders, as in a back squat and then have the 100 kg equivalent flywheel load attached with a waist harness, the body's centre of gravity (COG) will be lower in the FRT option, as having a weight higher, increases the height of the athletes COG. A lower COG is known to result in greater stability, and therefore the assumption of less likelihood of injury. Furthermore, the biomechanical benefits of a body harness in flywheel training can decrease the technical skills for correct movement implementation (24). So, for runners that are taller and/or weaker, FRT is a very safe training option.

Metabolic/Cardiovascular

Raeder and colleagues (26) analysed the neuromuscular, physiological and perceptual responses to different resistance training modes during a dynamic squat protocol. In terms of metabolic and perceptual demands, FRT produced significantly ($p \leq 0.05$) higher blood lactate concentration (>12 mmol·L^{-1}) compared to other training modes (traditional, eccentric overload, plyometrics and drop sets). This corresponded to FRT also having the highest perceptual RPE response. In terms of FRT, the crucial factor for eliciting higher metabolic responses may be related to time under tension (26) and greater muscle activation associated with FRT (8, 22). This may be beneficial for athletes who are short on time and want to achieve a high workload in a short amount of time.

In terms of cardiovascular adaptations, Banks and colleagues (3) compared 10-weeks of TRT and FRT in young healthy men. The authors reported similar improvements in isometric strength (TRT = 11.43%, Hedges g (g) = 0.81, FRT = 9.39% , g = 1.03), however the cardiovascular outcomes were vastly different. TRT reduced cardiovagal baroreflex sensitivity (BRS) ($p = 0.003$, g = 0.94) and heart rate variability ($p = 0.009$, g = 0.88), compared to FRT group, which saw an increase in BRS ($p = 0.01$, g = 0.94) and heart rate variability ($p = 0.04$, g = 0.54), which is thought a positive adaptation as it indicates improved autonomic control and cardiovascular adaptability. Additionally, FRT resulted in a significant ($p = 0.006$, ES = 0.34) decrease (6.38%) in resting heart rate compared to the TRT group which increased (4.75%) after 10-weeks of training. These unfavourable cardiovascular changes in the TRT group suggest FRT may be a more suitable resistance training option for runners.

Flywheel Concentrics

When performing TRT sessions, researchers have shown that after overcoming inertia and accelerating the load, a lot of the movement (force/time profile) is spent in deceleration (see Figure 1). However, with FRT the resistance is constant through almost the entirety of the concentric phase allowing the individual to accelerate through most of the movement, resulting in greater total force production and therefore, greater adaptive benefits. Performing squats to plantar flexion/just prior to toe-off, results in a profile similar to a ballistic profile (see Figure 3C), similar to that seen in running and plyometrics, without the airborne phase. This has the additional benefit of increasing activity specific strength and power, without getting airborne and experiencing the landing impact forces that in some cases can be injurious.

Flywheel Eccentrics

Eccentric strength plays a crucial role in running, particularly in reducing the risk of injury and improving overall performance. Eccentric muscle actions occur when a muscle lengthens while contracting, such as during the landing phase of a running stride. Strengthening eccentrically loaded

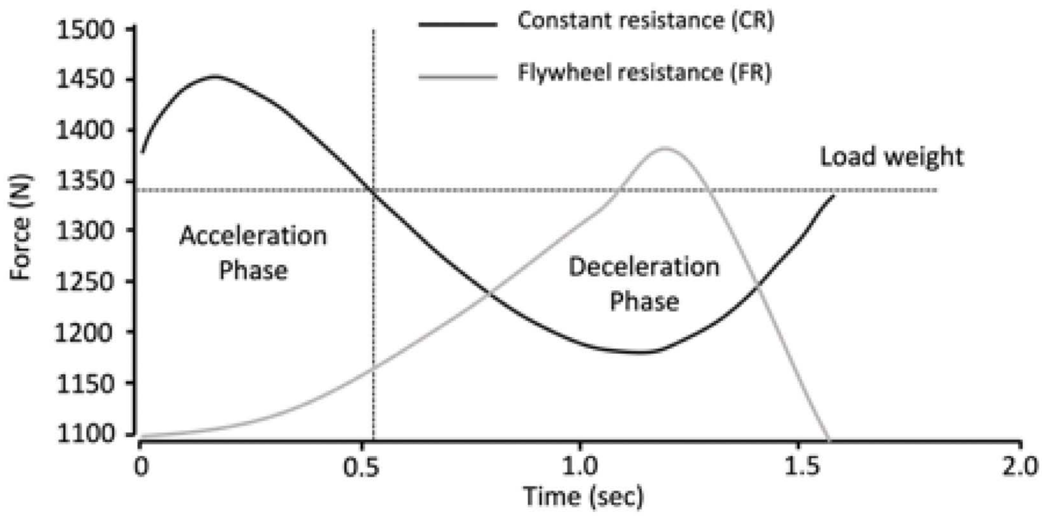

Figure 1. Force time profile of flywheel resistance versus constant resistance

muscles can improve an athlete's ability to control landing forces and prevent excessive stress on joints and tendons. Researchers have shown that eccentric strength training can improve running economy and speed, as well as reduce the risk of injuries such as hamstring strains and patellofemoral pain syndrome (17, 28, 32).

Given that flywheel training is known for the eccentric overload it provides, it would seem that this technology is ideally suited to enhance running performance. Furthermore, with practice you can choose where to eccentrically overload the contraction i.e., early, mid or in the late phase of the eccentric contraction. In terms of running, it likely makes sense to eccentrically overload the exercises in ranges of motion similar to running and in turn arrest the angular momentum of the flywheel early in the eccentric phase. Such a strategy will likely provide the most movement specific eccentric overload for running.

It needs to be noted that some flywheel companies have motorised technology (e.g. Exerfly) that have eccentric boost capability, providing supramaximal eccentric overloads from 1-80%. One of the benefits is that true eccentric overload needs to be greater than your concentric maximal strength i.e., supramaximal eccentrics. This motorised technology allows you to reach supramaximal overload on the eccentric phase in a safe and progressive manner by boosting the concentric terminal velocity by a predetermined percentage, during the ensuing eccentric phase. Researchers have shown that supramaximal eccentric training can increase maximal running speed, improve running economy, and reduce the risk of injuries such as Achilles tendinopathy (15). Further research is needed however, that explores the effects of eccentric boost flywheel training and the ideal dose-response relationship for improving running performance.

FLYWHEEL LOADING PARAMETERS FOR RUNNING PERFORMANCE

Strength training is an essential component of improving running performance. It helps in building muscular strength, which can assist runners in maintaining proper form and reduce the risk of injury, along with the benefits of endurance adaptions resulting in running economy gains. Recently, researchers have highlighted that complementing established cardiovascular training methods with resisted strength training methods, can produce positive outcomes in middle- and long-distance performances in runners and cyclists (7). Even though the research is limited (9, 35) the flywheel loading parameters that have resulted in significant strength gains and improvement in running performance are discussed in the following section.

Frequency/Volume

With regards to the flywheel studies, Festa and colleagues (9) used a single session per week prior to the endurance run session, whereas the athletes in Weng et al., (35) resistance trained three times per week. These sessions were completed 6-8 hours post each of the three run sessions limiting the interference effect of the competing aerobic-anaerobic adaptations. It would seem that 1-3 sessions per week, whether performed prior to or after the run, can provide sufficient overload in runners to promote positive adaptations. As can be observed, there is limited research on the frequency/volume of FRT compared to TRT to produce adaptation in runners.

Intensity

The recommended inertial load for flywheel resistance training depends on various factors, including an individual's training goals, strength levels, and training status. While specific guidelines for flywheel resistance training loads are limited, especially for runners, it is generally recommended to select a load that allows for controlled and proper execution of exercises while challenging the targeted muscle groups. With traditional resistance training, intensity is a function of mass/inertia, whereas flywheel intensity is a function of rotational inertia (I). This rotational inertia is the product of mass x the radius of the plate squared ($I = mr^2$). With this in mind, generally larger flywheels and therefore inertial loads (e.g., 0.10 $kg.m^2$) are used for training large muscle groups. For example, Weng at al., (35) utilised a 0.06 $kg.m^2$ inertial load on the flywheel apparatus for all participants. Festa et al., (9) did not specify the inertial load, but rather regulated intensity via perceived exertion on their yo-yo leg press, requesting maximum effort repetitions i.e., targets were 9-10/10. Typically lower inertial loads (0.025-0.050 $kg.m^2$), are used for high movement velocities/power gains, while higher inertial loads (>0.050 $kg.m^2$) should be used for greater strength-related gains (5, 19, 20, 30).

Duration

In terms of training intervention duration for FRT, both Weng et al., (35) and Festa et al., (9) utilised a 6-week training block, which was considered an ideal time frame for strength and conditioning adaption. It should be noted that this did not include the familiarisation and testing sessions, which in some cases may have some contribution to the overall adaptation. Nonetheless it would seem six weeks is an adequate duration in which adaptation can occur in runners.

Rest/Recovery

The American College of Sports Medicine suggested rest periods of 2-3 minutes between sets for exercises targeting muscular strength and power using traditional strength training methods (2). However, given the different repetition temporal dynamics of flywheel repetitions (i.e., no rest between eccentric and concentric phases and repetitions) the recommendations for traditional resistance may not be that applicable, and longer rest recovery periods may be optimal. Saying that, Weng et al., (35) and Festa et al., (9) utilised 3- and 3.5-minute recovery intervals in their experimental studies. Weng and colleagues (35) used a slightly lower intensity flywheel loading than the Festa et al., and thus the slightly shorter recovery interval was appropriate whilst still allowing reasonable time for recovery, lactic acid clearance and PCr resynthesis.

Exercise Type and Number

According to Beato et.al. (5) the first weekly flywheel training sessions should focus on strength development involving multiple sets with high inertial loads while subsequent flywheel sessions focus on power development with lower inertial loads and volume. Further according to the literature, multi-joint flywheel exercises such as squats, deadlifts and lunges should be prioritised when seeking strength and power development and transfer into sports specificity while single-joint flywheel exercises like leg curl, hip extension are implemented in effective injury prevention programs (4, 5, 18, 25).

The suggested number of exercises per session of FRT can vary depending on several factors, including training goals, time availability, and individual needs. While specific recommendations for the number of exercises in flywheel resistance training sessions are limited, it is generally advised to include a variety of exercises targeting different muscle groups to ensure overall muscular balance and development. The exercises used in the two training studies and identified as beneficial for runners were the squat (35) and leg press (9), both exercises were identified by the respective authors as motions which would have high potential for positive adaptions to running performance. However, multiple other exercises have been shown to enhance running performance and can be performed using flywheel technology (see Figures 2 and 3). The following are some recommended flywheel strength training exercises for runners:

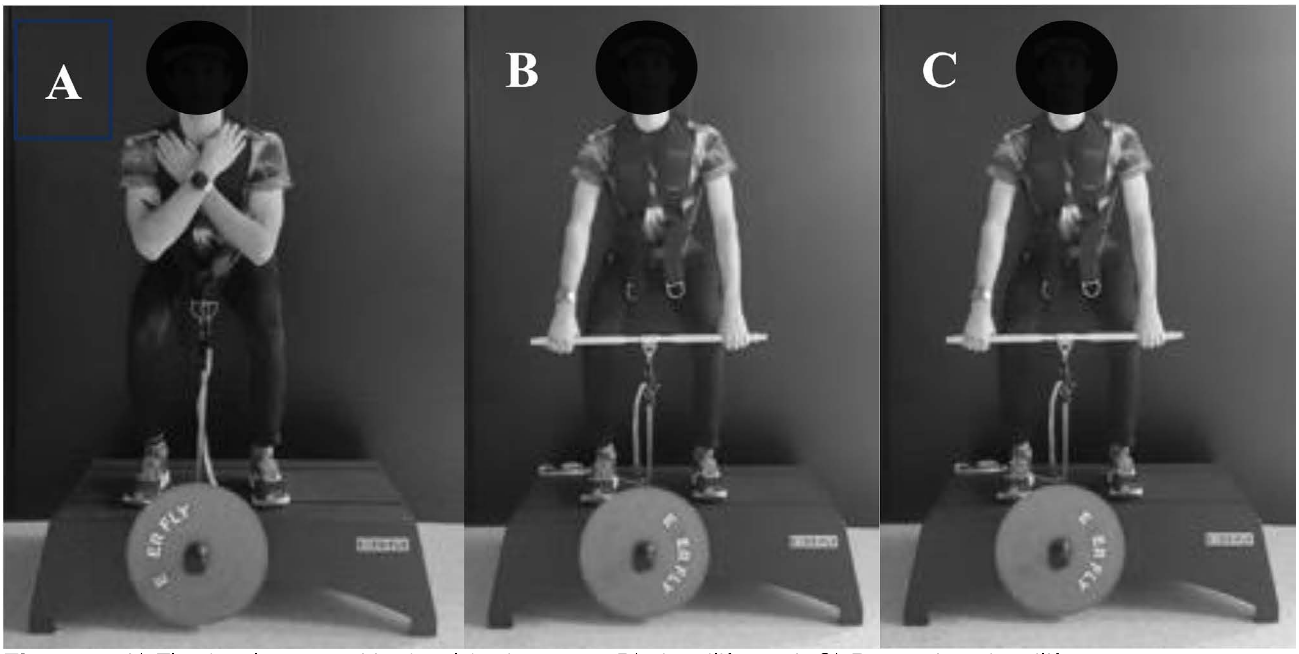

Figure 2. A) Flywheel squat with shoulder harness; B) deadlift; and, C) Romanian deadlift.

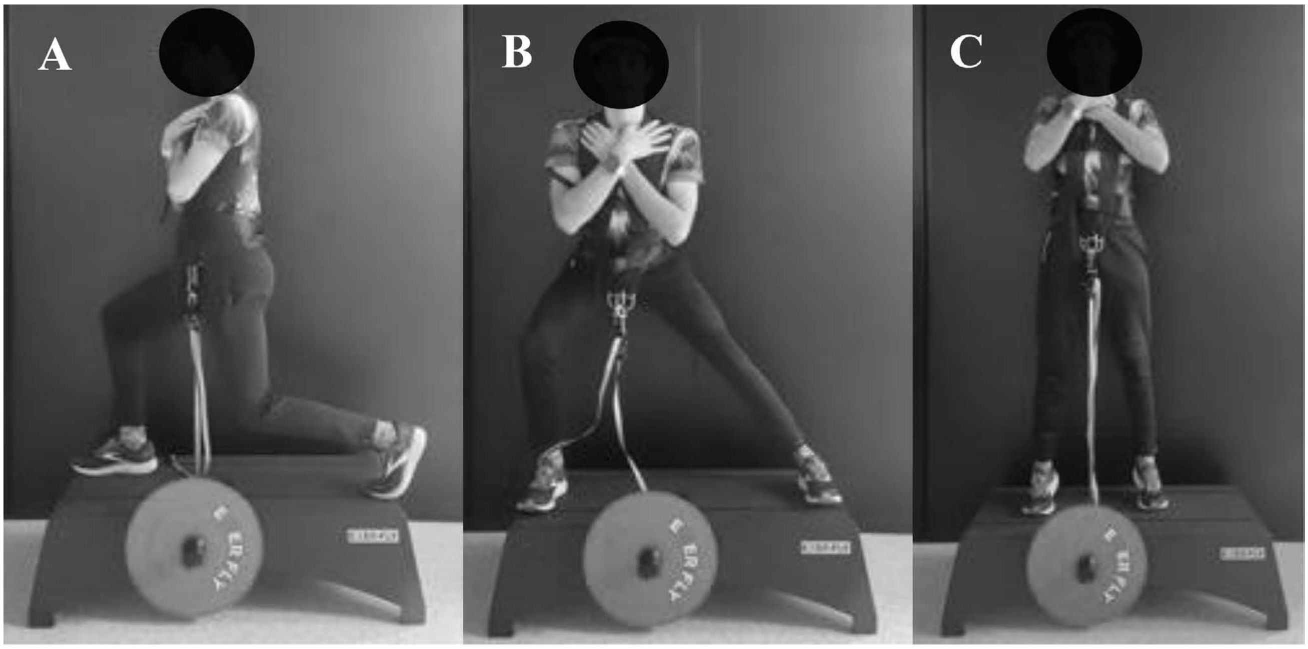

Figure 3. Shoulder harness flywheel A) front lunge, B) lateral lunge, and C) calf raises.

It needs to be noted that these exercises can and do offer a different stimulus to their traditional strength training counterparts due principally to the gravity independent nature of the FRT.

Training Adaptation

Both research groups that have used FRT for runners have reported significant ($p < 0.05$) improvements in running performance from FRT. Weng et al., (35) focused on the VO_2 capabilities of the individuals. For the control group (CG), no significant differences between pre and post testing at any of the three-percentage effort (65, 75 and 85% of VO_2 peak) tested, were observed. However, significant differences at each of the 3 efforts tested were observed for the FRT group (65%, Cohens *d* [ES] = 0.76, *p* =<0.0; 75%, ES = 1.04, *p* =<0.01; 85%, ES= 1.85 *p* =<0.01). They found significant differences ($p = 0.03$) when comparing running economy of the FRT to the CG. Similarly, Festa et al. (9) reported improvements in 2 km and 10 km times (average velocity 2 km: ES= 0.4, *p* = <0.05; average velocity 10km: ES=0.5, *p* =<0.05) post flywheel training.

SUMMARY

Flywheel technology utilises rotational inertia to generate resistive overload in a gravitationally independent manner. The concentric ballistic and eccentric overload it provides, can translate into benefits for running economy as flywheel loading strengthens the body, potentially reducing speed loss during impact due to increases in muscle stiffness. Flywheel resistance training also has additional unique benefits such as portability, autoregulation/individualisation, density/efficiency, injury/safety metabolic/cardiovascular and concentric/eccentric profiles, which make it a useful tool for runners interested in increasing strength to improve their performance. Finally, given the autoregulatory nature of the training stimulus in tandem with the ability to load the legs with shoulder or waist harnesses, it would seem a very safe form of training for the youth to elite runner.

As evidenced, the research into the benefit of FRT for runners is extremely limited, and it needs to be acknowledged that there are methodological limitations associated with the FRT papers (9, 35). Nonetheless, the preliminary evidence seems somewhat promising, especially given the results of Weng et al., (35) that compared FRT with TRT in elite runners. The positives of this paucity of research, are the opportunities for researchers to expand the knowledge base in this area without replication of past experimentation. For example, researchers could analyse the benefits of flywheel resistance training on endurance athletes over longer distances. The frequency of flywheel training needs investigation, increasing or decreasing the number of sessions to determine the dose-response for runners would seem important, and could differ across training status, sex, age, level of competition and other factors.

CONFLICTS OF INTEREST

John Ireland is a sport scientist at Exerfly.

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