Universidad Miguel Hernández de Elche

Programa de Doctorado en Deporte y Salud

TRAINING VARIABLES OF FLYWHEEL RESISTANCE TRAINING AND THEIR APPLICATION IN DIFFERENT STRENGTH AND CONDITIONING PROGRAMS

Doctoral thesis
A dissertation presented by

D. Pablo Asencio Vicedo

Directed by

Dr. Rafael Sabido Solana

Co-directed by

Dr. Francisco Javier Moreno Hernández

Elche, 2024

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La presente tesis doctoral, titulada “Training variables of flywheel resistance training and their application in different strength and conditioning programs*”*, es un compendio de cuatro artículos publicados en revistas indexadas en el *Journal Citation Reports* de la *Web of Science*:

1. Sabido, R., Hernández-Davó, J. L., García-Valverde, A., Marco, P., & Asencio, P. (2020). Influence of the Strap Rewind Height during a Conical Pulley Exercise. *Journal of Human Kinetics*, *74*(1), 109–118. http://doi.org/10.2478/hukin-2020-0018

2. Asencio, P., García-Valverde, A., Albaladejo-García, C., Beato, M., Moreno, F. J., & Sabido, R. (2024). Analysis of Concentric and Eccentric Power in Flywheel Exercises Depending on the Subjects’ Strength Level and Body Mass. *Journal of Strength and Conditioniong Research,* 10-1519. https://doi.org/10.1519/JSC.0000000000004818

3. Asencio, P., Hernández-Davó, J. L., García-Valverde, A., & Sabido, R. (2022). Effects of flywheel resistance training using horizontal vs vertical exercises. *International Journal of Sports Science and Coaching*, *19*(1), 410–416. https://doi.org/10.1177/17479541221135372

4. Asencio, P., Moreno, F. J., Hernández-Davó, J. L., & Sabido, R. (2024). Effects of variable intensity and constant intensity flywheel resistance training programs on specific soccer players’ performance. *Frontiers in Physiology*, *15*. https://doi.org/10.3389/fphys.2024.1375438

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El Dr. D. Rafael Sabido Solana, director, y el Dr. D. Francisco Javier Moreno Hernández, codirector de la tesis doctoral titulada "*Training variables of flywheel resistance training and their application in different strength and conditioning programs*"

INFORMAN:

Que D. *Pablo Asencio Vicedo* ha realizado bajo nuestra supervisión el trabajo titulado "*Training variables of flywheel resistance training and their application in different strength and conditioning programs*" conforme a los términos y condiciones definidos en su Plan de Investigación y de acuerdo con el Código de Buenas Prácticas de la Universidad Miguel Hernández de Elche, cumpliendo los objetivos previstos de forma satisfactoria para su defensa pública como tesis doctoral.

Lo que firmamos para los efectos oportunos, en Elche, el 26 de junio de 2024.

Director de la tesis	Codirector de la tesis:
Dr. *Rafael Sabido Solana*	Dr. *Francisco Javier Moreno Hernández*

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El Dr. *Francisco Javier Moreno Hernández*, Coordinador del Programa de Doctorado en Deporte y Salud

INFORMA:

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Lo que firmo para los efectos oportunos, en Elche, el 26 de junio de 2024.

Prof. Dr. Francisco Javier Moreno Hernández

Coordinador del Programa de Doctorado en Deporte y Salud

FINANCIACIÓN

Las fuentes de financiación que el estudiante D. Pablo Asencio Vicedo ha recibido para llevar a cabo el proyecto de investigación vinculado a la presente Tesis Doctoral corresponden a las ayudas para los contratos predoctorales para la formación de Personal Investigador. Estas ayudas pertenecen al proyecto PID2019-109632R8-100, que incluye una ayuda adicional de 6.860 € para la financiación de las estancias de movilidad correspondiente a la convocatoria de 2020 (PRE2020-091858). Este contrato predoctoral ha sido cofinanciado por el Fondo Social Europeo.

‘’Pasaré la vida entera siempre dispuesto a empezar.

Siempre hay nuevas primaveras.

Soy curioso, no voy a cambiar’’

Manolo García

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List of abbreviations

CMJ: countermovement jump

COD: change of direction

CONC: concentric

ECC: eccentric

EOL: eccentric overload

ICC: intraclass correlation coefficient

PPconc: concentric peak power

PPecc: eccentric peak power

RT: resistance training

SSC: stretch shortening cycle

1RM: one repetition maximum

VR: vertical rope

HR: horizontal rope

MIX: mixted rope

VI: variable intensity

CI: constant intensity

10-m sprint: ten meters sprint

30-m sprint: thirthy meters sprint

M-505D: modified 505 test with dominant leg

M-505ND: modified 505 test with non-dominant leg

List of figures

Nota: Las figuras insertadas al inicio de cada sección de esta tesis doctoral son de fuente propia.

Resumen

En el rendimiento deportivo, hay algunas variables como la capacidad de salto, la fuerza máxima, la velocidad y el cambio de dirección que son determinantes para los atletas de diversas disciplinas deportivas. Estas variables están condicionadas por el ciclo de estiramiento-acortamiento (SSC), que a su vez se compone de una serie de procesos fisiológicos que explican la producción de potencia y fuerza. Las acciones deportivas específicas incluyen contracciones excéntricas (EXC) muy intensas realizadas a alta velocidad. Debido a la importancia de las mismas en el contexto deportivo, surgió el entrenamiento isoinercial (EI). Pese a que ha ganado mucha atención en el mundo de la fuerza y el acondicionamiento en los últimos años, la programación de la intensidad y la individualización según los objetivos, el contexto de entrenamiento (teniendo en cuenta el tipo de dispositivo o el tipo de ejercicio) y las características del atleta son limitadas. A pesar de una mayor investigación sobre variables mecánicas en el (EI), muchos estudios pasan por alto el impacto de la longitud de la cuerda y la altura de recogida de la misma en las variables de potencia, lo que dificulta el diseño óptimo de los programas de entrenamiento. Además, el conocimiento insuficiente sobre la intensidad, la dirección de la carga y la especificidad de la fuerza requiere más estudios para mejorar las adaptaciones del EI a medio y largo plazo. Los estudios tienen como objetivo abordar las lagunas en la comprensión de la FRT y su impacto en el rendimiento deportivo. El *estudio 1* investiga la influencia de la longitud y la altura de recogida de la cuerda en las variables mecánicas del EI durante los ejercicios de polea cónica y encontró que se logra mayor producción de potencia cuando la cuerda está alrededor de la parte más ancha del cono. Por el contrario, se encontraron valores más altos de sobrecarga excéntrica (SE) en la parte más estrecha del cono. El *estudio 2* explora el impacto de las características del atleta y el tipo de ejercicio en los resultados de rendimiento del EI. Los principales hallazgos son que existen diferentes perfiles de inercia-potencia dependiendo del tipo de ejercicio, la fase del movimiento y nivel de entrenamiento, pero estas diferencias no están influenciadas por la masa corporal (MC). El *estudio 3* compara los efectos de diferentes direcciones de carga (vertical, horizontal o mixta) sobre ganancias de fuerza específicas, con mayores incrementos en los niveles de fuerza en sentadilla con ejercicios dirigidos verticalmente. Sin embargo, no hubo diferencias aparentes entre las condiciones de carga para promover mejoras en el salto y el rendimiento COD. Por último, el *estudio 4* compara dos programas de FRT, intensidad variable (VI) e intensidad constante (CI), en diversas tareas de rendimiento en jugadores de fútbol mostrando mejoras en algunas variables de rendimiento en ambos grupos pero con mejores resultados en la variable sprint de 10 metros para el grupo que entrenó con intensidad constante. Los resultados de los estudios indican hallazgos significativos con respecto a la influencia de la longitud de la cuerda y la altura de recogida de la cuerda en las variables mecánicas del FRT, los efectos de las características del atleta y el tipo de ejercicio en los resultados de rendimiento del FRT, y el impacto de diferentes condiciones e intensidades de carga del EI en las ganancias de fuerza específicas. En resumen, los estudios contribuyen a comprender la manipulación óptima de las variables en los programas EI y su impacto en el rendimiento deportivo, abordando lagunas en el conocimiento actual y proporcionando ideas para futuras direcciones de investigación.

Palabras clave: *entrenamiento isoinercial, pico de potencia, sobrecarga excéntrica, dirección de la fuerza, intensidad del entrenamiento.*

Abstract

There are some key variables in sports performance (i.e. jump ability, maximum strength, speed, and change of direction ability) that are highlighted as crucial determinants of athletic success across various sports disciplines. To improve this variables, the physiological processes around stretch-shortening cycle (SSC) are linked with the increments in power and force production. Specific sport-actions include very intense eccentric (ECC) actions, which are related with SSC. Due to the importance of high velocity ECC actions in sports athmosphere, flywheel resistance training (FRT) emerged. Besides that FRT has gained a lot of attention in the world of strength and conditioning, intensity programming and individualization according to the objectives, training context (i.e. type of device or type of exercise) and athlete's characteristics is limited. Despite increased research on mechanical variables in flywheel resistance training (FRT), many studies overlook the impact of rope length and strap rewind level on power variables, hindering optimal program design. Additionally, insufficient knowledge about loading conditions and strength specificity necessitates further study to improve medium- and long-term FRT adaptations. The studies aim to address gaps in understanding FRT and its impact on athletic performance. *Study 1* investigates the influence of rope length and strap rewind height on FRT mechanical variables during conical pulley exercises and found that higher power outputs are achieved when rope is around the widest part of cone. In contrast, higher eccentric overload (EOL) values were found in the narrowest part of the cone. *Study 2* explores the impact of athlete characteristics and exercise type on FRT performance outcomes. The main findings are that there are different inertia-power profiles depending of the type of exercise, phase of movement and training level, but this differences are not influenced by body mass (BM). *Study 3* compares the effects of different FRT loading conditions (vertical, horizontal of mixted) on specific strength gains, with higher increments in squat strength levels with vertical-directed exercises. However, there were no apparent differences between loading conditions in promoting improvements in jumping and COD performance. Lastly, *study 4* compares two FRT programs, variable intensity (VI) and constant intensity (CI), on various performance tasks in soccer players showing improvements in some performance variables in both groups but with better results in 10-m sprint variable for the CI group. The results of the studies indicate significant findings regarding the influence of rope length and strap rewind height on FRT mechanical variables, the effects of athlete characteristics and exercise type on FRT performance outcomes, and the impact of different FRT loading conditions and intensities on specific strength gains. In summary, the studies contribute to understanding the optimal manipulation of variables in FRT programs and their impact on athletic performance, addressing gaps in current knowledge and providing insights for future research directions.

Key words: *flywheel resistance training, power output, eccentric overload, force direction, training intensity .*

1. GENERAL INTRODUCTION

Imagen de fuente propia

1. General introduction

1.1. Key variables in sport performance

In high-performance sports, a multifaceted approach is essential for understanding the key performance variables that significantly impact outcomes. Numerous studies have highlighted the correlation between different performance variables (e.g. jump, change of direction – COD –, sprint, power and strength ability) and athletes' success (see Figure 1) across diverse sport disciplines (Suchomel et al., 2016).

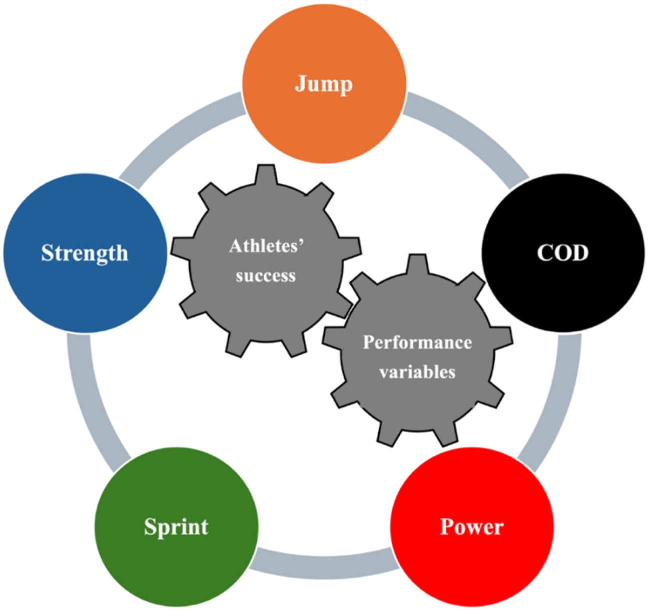

Figure 1. Diagram of variables that have been shown to correlate with sports performance.

Among these variables, jump ability stands out as one of the most extensively researched. In numerous intermittent sports, jump ability plays a decisive role (Stølen et al., 2005; Kruger et al., 2014; Ziv et al., 2009) and has been used as a predictor of sporting success (Harry et al., 2018). The relationship between countermovement jump (CMJ) variables (e.g. jump height or power) and athletic performance has been demonstrated in previous research (Harry et al., 2018) highlighting its importance as a predictor of explosive strength.

Other determinant of athletic performance is maximum strength, measured as a one-repetition maximum (1RM). Higher values of muscular strength are, in turn, positively associated with specific strength markers (e.g., power output or rate of force development) (Suchomel et al., 2016). Furthermore, the same authors have emphasized the positive relationship between maximal strength and overall sports performance (i.e. jumping, sprinting and COD ability), specific sport skill performance and decreased injury rates.

Speed is another key performance metric, with previous research highlighting the role of the ability to accelerate and sprint time in intermittent sports (e.g. football) (Cronin & Hansen, 2005; Haugen et al., 2014). This variable could be determined by the relationship between power and body weight (Cronin & Hansen, 2005). Moreover, previous research showed that speed improvements can contribute significantly to an athlete's ability to perform during specific sports contexts (Haugen et al., 2014).

Several authors have suggested that COD ability is essential for successful participation in intermittent sports (Gil et al., 2007; Reilly et al., 2000). Some studies have supported this by using COD performance as a criterion for player selection in intermittent sports (Gil et al., 2007; McGee et al., 2003). Several considerations merit attention when developing COD performance, including the specificity of maneuvers, the length and quantity of COD actions within the task. The above observations have sparked an interest in further research into this variable (Nygaard et al., 2019).

Consequently, improving the key variables highlighted above should be the cornerstone of training programs, particularly during the pre-season (Hartman et al., 2015), when strength and conditioning coaches have more time (e.g., 3–5 weeks) to develop players' fitness (Núñez et al., 2018).

1.2. Importance of stretch-shortening cycle in training process

All the previously mentioned performance variables are composed of the cyclical interplay between muscle eccentric (ECC), isometric and concentric (CONC) phases. This sequence of ECC and CONC contractions is known as the stretch-shortening cycle (SSC), which plays a crucial role during explosive activities (i.e. sprinting, jumping and COD) (Komi, 2003) to maximize power and force production (Haff & Nimbus, 2012).

According to Turner & Jeffreys (2010), several physiological processes help to explain SSC phenomenon, including elastic strain storage, involuntary processes, active range of movement, length-tension relationships, preactivity and inter-muscular coordination. Most of these mechanisms are tightly linked with the ECC contractions. Firstly, ECC contractions contribute to the increased storage of elastic energy during SSC movements. Secondly, training methodologies based on ECC contractions could improve the series elastic component presented by Hill (1938). Thirdly, the elastic properties of tendons play a crucial role in power production, stiffness enhancement, and overall efficiency. Research indicates that eccentric training can be beneficial in improving tendon stiffness and properties (Douglas et al., 2017). Lastly, manipulating the length-tension curve to optimize muscle behavior across a broad range of lengths can position the muscle advantageously for force production (Turner and Jeffreys, 2010).

Consequently, research has elucidated the significance of the SSC phenomenon in enhancing athletic performance, demonstrating its role in improving movement efficiency, optimizing muscular coordination, and increasing energy storage and release capabilities (Harry et al., 2018). In addition, adaptations after training interventions focusing on the SSC mechanism have been linked with improvements in overall athletic performance (Turner and

Jeffreys, 2010). In addition , ECC could contribute to the increased storage of elastic energy during SSC movements and play a crucial role in improving overall athletic performance.

1.3. Eccentric actions characteristics and sport specific tasks

Given the close connection between ECC actions and their impact on the SSC, there has been a notable increase in the utilization of eccentric training in recent years to enhance performance in SSC-related tasks.

It has been reported that ECC contractions have unique characteristics (see Figure 2). First, they require less motor unit activation and consume less oxygen and energy for a given muscle force output than CONC contractions (Hody et al., 2019). Furthermore, Duchateau and Baudry (2014) reported that neural strategies for ECC contractions considerably differ from CONC and isometric contractions. ECC contractions required fewer motor units for the same work when compared with CONC and isometric contractions.

According to these characteristics, greater force production capacity has been reported for ECC in comparison with CONC actions (Sogaard et al., 1996). For this reason, using the same absolute load would lead to a lowered stimulus for ECC actions. This issue theoretically places traditional resistance exercises (e.g. free weight, weight stack machines), where the same absolute load is lifted and lowered, at a disadvantage compared with other types of exercise that incorporates a greater emphasis on the eccentric phase of the movement (Hoppeler and Herzog, 2014).

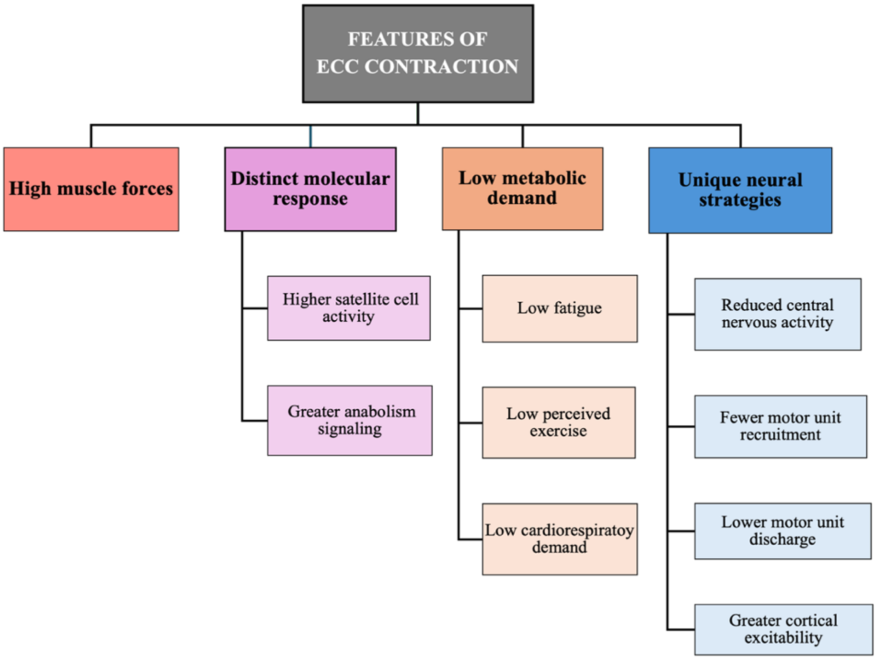

Figure 2. Characteristics of ECC contractions.

Different methodologies of resistance training (RT) have emerged to cover the need to enhance the movement's ECC phase. Traditionally, methodologies based on time under tension (TUT), like tempo eccentric training (Suchomel et al., 2019), were put into practice. Tempo eccentric training modifies the pace of CONC and ECC with the objective of eliciting a specific response (Suchomel et al., 2019). However, this traditional methodology with longer CONC and ECC phases (e.g., lift every repetition of the exercise with a specific cadence for each phase) is not reproducible in a sports context, where actions often last less than 200 ms (Komi, 2000).

Nonetheless, supramaximal eccentric training has been implemented to take advantage of greater force production in ECC phase. This training form incorporates controlled ECC contractions with loads ranging from 100% to 150% of 1RM (Buskard et al., 2018), based on the elevated muscle tension and greater structural damage than traditional methods. In addition, a meta-analysis by Buskard (2018) reported improvements in 1RM in both novice and expert subjects, suggesting special attention to weaker subjects due to the muscle damage that this methodology can cause.

Another way to enhance the ECC phase of the movement is variable resistance training. This method involves adjusting the external resistance throughout the range of motion and exercise, and it has garnered increased attention over the past two decades (Wallace et al., 2018). Various strategies can be employed to achieve this objective, including the use of cam-based machines (McMaster et al., 2009) and incorporating chains and elastic bands onto the bar. Firstly, cam-based systems are engineered to alter the external movement arm, such as its length or radius, corresponding to the movement arm at different points of the motion. Secondly, the implementation of chains and elastic bands to the bar aims to modify the ascending and descending strength curves (Wallace et al., 2018). These approaches have been extensively studied in both athletic populations and untrained subjects and have demonstrated their efficacy in several ways, including the modification of strength curves, greater eccentric loading leading to higher concentric torque, altered TUT, and preferential adaptations of type II muscle fibers.

Lastly, in line with training methodologies proposed to enhance the demand on the ECC phase, with pneumatic resistance being one such approach. Pneumatic resistance devices use compressed air to maintain a constant force output during movement (Avrillon et al. 2017), essentially removing the inertia component of the ECC phase (Frost et al., 2016). Research has demonstrated significant improvements in strength and power across various demographics, including healthy individuals, the elderly, and athletes (Avrillon et al., 2017; Frost et al., 2016; Maroto-Izquierdo et al., 2022).

1.4. Flywheel resistance training

Due to the benefits of ECC actions and the importance of athletes executing this phase at maximal velocity, flywheel resistance training (FRT) emerged. FRT uses rotating flywheel discs or cones (depending on the type of device) to provide resistance (Beato et al.

2024). The main difference between these devices is the axis of rotation, being constant in the discs and variable in the cone as the rope is coiled around the axis (Muñoz-López et al., 2021). Consequently, conical pulleys allow greater movement velocities while conducting specific and multidirectional movements (Gonzalo-Skok et al., 2017; Nuñez et al., 2017). The CONC action is initiated by pulling the strap connected to the shaft of the device, accelerating the flywheel/cone. Quickly, once the strap starts to rewind again around the axis of rotation, an ECC action is performed to decelerate the inertia (Beato et al. 2024). When braking action is performed in the last third of the movement, the flywheel device allows for brief episodes of the so-called "eccentric overload" (EOL) (see Figure 3). This phenomenon occurs when the power values of ECC phase are greater than CONC phase power values.

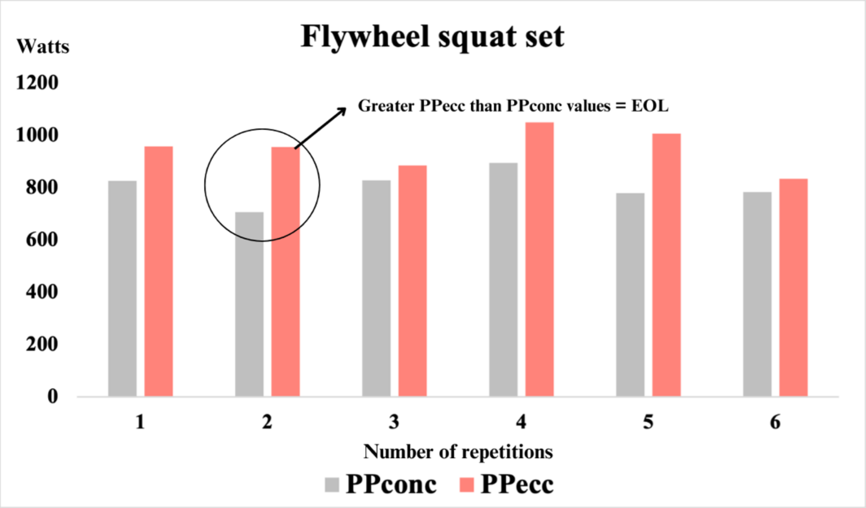

Figure 3. Episodes of EOL during flywheel squat set. PPconc: concentric peak power; PPecc: eccentric peak power.

A classic study about FRT reported the usefulness of this methodology to induce morphological adaptations (e.g., muscular hypertrophy) in healthy and athletic populations (Norrbrand et al., 2008). Besides that, a recent flywheel consensus statement has recommended FRT as a means to improve acceleration and deceleration speed, as well as sprint and COD ability (Beato et al., 2024). In addition, there is evidence about the positive effects of FRT on strength (Askling et al., 2003; Norrbrand et al., 2010; Raya et al., 2021; Allen et al., 2023), power (Coratella et al., 2019, Fiorilli et al., 2020; Raya et al., 2021; Allen et al., 2023), COD (Coratella et al., 2019, Fiorilli et al., 2020; de Keijzer et al., 2022), CMJ (de Keijzer et al., 2022; Allen et al., 2023) and sprinting ability (de Keijzer et al., 2022; de Hoyo et al., 2015) in different populations. In relation to neuromuscular and structural adaptations, several researchers (Askling et al., 2003; Tous-Fajardo et al., 2006; de Hoyo et al., 2015; Beato et al., 2024) have proposed that FRT could mitigate the risks of muscular and articular injuries in sports populations.

Given the aforementioned benefits associated with FRT, and its relevance for improving dynamic athletic performance, this methodology has gained a lot of attention in the world of strength and conditioning (Maroto-Izquierdo et al., 2017; Blazek et al., 2019). The nature of FRT allows it to mimic many sporting actions (Raya et al., 2021). Sports movements demand the production of maximal power in unpredictable and variable contexts, with an emphasis on ECC and multidirectional components (Gonzalo-Skok et al., 2017). Thus, considering the principle of specificity and the possibility of FRT to perform multi-planar exercises that accentuate force and power production during the ECC phase, FRT should be more present in resistance training workouts tailored to athletes, particularly of intermittent sports, such as football (Beato et al., 2021; Gonzalo-Skok et al., 2017).

1.5. FRT intensity prescription and individualization

Three methods have been proposed for practitioners to prescribe exercise intensity with flywheel resistance technology: 1) moment of inertia (i.e. inertial load); 2) power outputs (i.e. CONC, ECC, or EOL); 3) mean and peak velocity (Maroto-Izquierdo et al., 2021). Some articles reported the influence of inertial loads on force and power output performance during flywheel resistance exercises (Martínez-Aranda et al., 2017; Piqueras-Sanchiz et al., 2019; Sabido et al., 2018; Vazquez- Guerrero et al., 2016). Specifically, light inertial loads allow for greater CONC and ECC power output than high inertial loads. Besides, when performed properly, flywheel exercises allow EOL, especially with high inertial loads. As power is the product of velocity and force (Cormie et al., 2011), athletes' strength level is a determinant for increasing power output (Baker, n.d.; Bompa & Haff, 2009). Previous research showed an inverse relationship between load and power outputs and a positive relationship between load and EOL (McErlain-Naylor & Beato, 2021; Piqueras-Sanchiz et al., 2020; Sabido et al., 2018). It is common to report mechanical output data for both phases, as well as their ratio (ECC/CONC ratio), which assesses the presence or not of an EOL (Norrbrand et al., 2008). Furthermore, CONC and ECC velocities (mean and peak velocity) were also proposed for FRT prescription (McErlain-Naylor and Beato, 2020). The application of rotary encoders that provide information about the power and velocity of the flywheel is common among practitioners. CONC or ECC linear velocity and power output of each repetition with each load are useful to establish individual inertia-velocity or inertia-power profiles for FRT exercises. However, the inertia–power profile is the most commonly used approach because of the difficulty of assessing velocity in practical scenarios (e.g., lack of time or technology) (Maroto-Izquierdo et al., 2021). The use of an inertia-power profile to individualize peak power output is supported by previous authors (de Hoyo et al., 2015; Maroto-Izquierdo et al., 2021), who have used this approach to maximize the benefits of squat exercises.

Although there is some research on FRT monitoring (Maroto-Izquierdo et al., 2021), we do not have exhaustive evidence for optimization of mechanical outputs during FRT according to training context (e.g., speed of CONC and ECC phases, type of device, type of movement or loading conditions) and athlete's characteristics (e.g., body mass – BM, initial strength, familiarization with the given exercise) (Beato & Dello Iacono, 2020; Beato et al., 2021). Therefore, it seems that a relationship exists between higher lower limb power output and sport-specific ability (Baker, n.d; Deven et al., 2010; Nimphius et al., 2010). It is important to remember that peak power can vary depending on some variables, such as the athlete's strength level (Slimani & Nikolaidis, 2017), training experience (Cormie, 2011; James, 2018) or type of exercise (Cronin & Hansen, 2005). From a training perspective, one criterion to identify the right training intensity is to evaluate the load that allows subjects to achieve peak power in a specific exercise (Cormie et al., 2011; Gonzalo-Skok et al., 2017).

The importance of reaching EOL values should be highlighted, as force improvement after the FRT program is greater with the existence of EOL during training (Nuñez and Saez de Villarreal, 2017). To achieve this goal, in conical pulley devices (see Figure 4), exercise intensity can be adjusted through two different modes: (a) by adding or removing any number of weights located on the edge of the flywheel and (b) by selecting one of the four height levels that will change the location of the pulley, height level 1 being the upper position (where the rope coils around the narrowest diameter of the cone) and level 4 being the lowest position (wider part of the cone) (Moras et al., 2018; Moras et al., 2019). Although unreported in most studies, the selection of the height level influences the geometrical factor (i.e., radius) of the conical pulley, which consequently affects force production (Norrbrand et al., 2008).

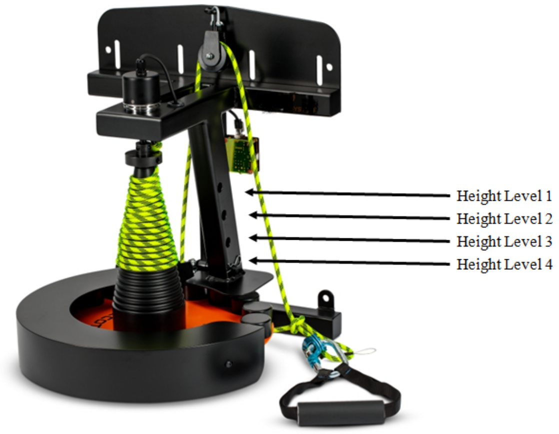

Figure 4. Picture of the conical pulley and the position of the four different height levels.

However, due to the novelty of using conical pulleys, little research has been conducted to answer the question of how modifying relevant variables can affect the changes in flywheel resistance exercises. To the best of our knowledge, only Vazquez- Guerrero et al. (2016) studied the influence of the height level used in the conical pulley. In that study, greater velocities but lower force values were observed when using a greater radius of the cone. However, previous studies have not analyzed power output to different heights. In addition, by modifying the rope length, conical pulley exercises can be performed closer or farther from the device. Whether this variable also affects power output has not previously been analyzed.

1.6. The relevance of the force orientation in FRT

In addition, sport-specific actions (i.e. CMJ or COD ability) are performed in different movement planes. Flywheel devices offer the possibility to work in different movement planes with different force orientation using multiplanar exercises. These characteristics make FRT highly specific and a better choice for replicating sports-specific actions (Raya-González et al., 2021; Tesch et al., 2017). Gonzalo-Skok et al. (2019) examined the influence of vertical and horizontal plyometric training on COD performance (e.g., V-cut test) in intermittent sports players, showing no significant differences between the two training methods. Conversely, Ramirez-Campillo et al. (2015) suggested a mixed method (i.e., a combination of horizontal and vertical plyometric exercises) as the most appropriate to improve COD performance. Despite the considerable number of articles evaluating changes in jumping performance, research assessing the influence of FRT on horizontal versus vertical resistance exercises on COD performance remains scarce.

Traditionally, different methodologies have been proven to improve CMJ performance, including traditional resistance training (e.g., free weights, stack machines) (Bauer et al., 2019), plyometrics (MacDonald et al., 2012; Manovias et al., 2016), olympic weightlifting movements (Tricoli et al., 2005), isokinetic resistance training (Papadopoulos et al., 2014) and accentuated eccentric loading. However, not all of the above-mentioned resistance training methods have been associated with enhanced COD performance (Brughelli et al., 2008), possibly due to the type of exercise and the load used. A possible explanation for these divergent findings is the different orientation of force application (e.g., vertical in CMJ vs horizontal in COD condition) (Petre et al., 2018; Morán et al., 2021). However, in spite of the previous promising performance improvements following FRT, research assessing the influence of force orientation during flywheel exercise is limited.

1.7. FRT programming: a lack of evidence

Exercise prescription has been defined as manipulating training variables within different training phases to achieve specific adaptations (Lorenz et al., 2015). Resistance training programs should consider various training variables over time (Kraemer & Ratamess, 2009), as well as different strategies to optimize the force–time relationship and consequently increase performance in sport-specific tasks (Suchomel et al., 2016). As such, programs should thoroughly control variables such as intensity, volume, density, frequency or exercise selection (Zatsiorsky et al., 2020). Training intensity has received the greatest attention in strength training programs. The relationship between intensity and volume dictates the physiological and biomechanical demands during resistance exercise. Therefore, a combination of training variables is essential for optimizing training outcomes, achieving fitness goals and reducing the risks of overtraining (Kraemer & Ratamess, 2004).

Despite the effectiveness of FRT at improving athletes' performance, supported by previous research (Beato et al., 2021), only a few variables pertinent to FRT (mainly intensity/inertial load) have been studied in the scientific literature. This scarcity of relevant research signifies a lack of knowledge about the optimal manipulation of basic variables during an FRT program. Most studies (de Hoyo et al., 2015; Sabido et al., 2018) used a constant load approach (same inertial load during FRT), finding improvements in different performance variables (e.g. CMJ, sprint or 1RM squat). Moreover, FRT effectiveness over medium- and long-term remains unexplored. Due to the lack of research on the possible effects of different FRT programs, it is important to determine how to modify different training variables and the specific moment when intensity should be changed during an FRT program.

1.8. Summary of the research problems

As mentioned earlier in this chapter, despite the increment in research on mechanical variables in FRT and sports performance in recent years, there are some limitations to their applications in medium- and long-term programs. Many of the studies did not consider the influence of rope length and strap rewind level on power variables. Meanwhile, both variables may influence the optimization of the design of flywheel training programs. Moreover, other factors could be crucial to individualized FRT prescription (e.g. type of exercise, experience level or BW). The absence of research on mechanical variables can lead to suboptimal medium- and long-term training program design. In addition, there is not enough knowledge about the usefulness of different loading conditions and the specificity of strength gains. According to methodological bases of FRT programs (Beato et al., 2021), there is a need to compare the effect between different types of FRT programs (mainly changing volume and intensity along the microcycles) in medium- and long-term adaptations. Prior to this thesis, it was difficult to make predictions about how FRT variables, particularly intensity and loading conditions, can influence the effect of different training programs. Hence, the popularity of FRT in recent years and this lack of knowledge about how to prescribe FRT programs have motivated the development of this doctoral thesis.

2. RESEARCH OBJECTIVES AND HYPOTHESES

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2. Research objectives and hypotheses

2.1. General objectives

The previously discussed limitations mentioned in the scientific literature on FRT underscore a significant gap in understanding the training variables that most influence this methodology. With the challenge of improving the application of strength training with flywheel devices, the main objectives of this doctoral thesis are: *(i) to analyze the mechanical variables of FRT and the impact of athletes' characteristics such as body mass (BM) and strength level have on power outputs, and (ii) to explore the influence of some training variables (e.g. loading conditions and intensities' variation) in sport-specific tasks.*

To reach this objectives, studies *1, 2*, *3* and *4* were performed. *Study 1* assessed the influence of three different rope lengths (1.5, 2.5, and 3.5 meters) and four different height levels (L1, L2, L3 and L4) on different FRT mechanical variables during conical pulley seated and stand up row exercises. *Study 2* studied the influence of variables such as BM, training level or type of exercise (e.g. squat and split squat) in FRT performance outcomes. *Study 3* compared the effect of three different FRT programs in specific strength gains. The difference between FRT programs were the different loading conditions (horizontal, vertical or mixed) performed. Finally, *Study 4* compared two different approaches to prescribe training intensity in FRT (CI and VI). The studies titles are as follows:

- Study 1: *''Influence of the strap rewind height during a conical pulley exercise''*

- Study 2: *''Analysis of concentric and eccentric power in flywheel exercises depending on the subjects' strength level and body mass''*

- Study 3: *''Effects of flywheel resistance training using horizontal vs vertical exercises''*

- Study 4: *''Effects of variable intensity and constant intensity flywheel resistance training programs on specific soccer players' performance''*

2.2. Specific objectives

This section has been structured following the order of the four studies that have been included in this doctoral thesis:

Study 1:

1) To analyze the influence of using three different rope lengths during conical pulley resistance exercises on concentric peak power, ECC peak power and EOL.

2) To analyze the influence of different heights of strap rewind during conical pulley resistance exercises on concentric peak power, ECC peak power and EOL.

Study 2:

3) To analyze how mechanical outputs are affected by the athletes' BM, strength level, and the exercise performed.

4) To compare how mechanical outputs are affected in bilateral and unilateral exercises.

Study 3:

5) To assess the usefulness of different loading conditions (i.e., vertical, horizontal, and mixed) during different flywheel exercises on squat strength gains, vertical jump increases, and COD performance.

6) To check if adaptations in these variables depended on the loading conditions used.

Study 4:

7) To compare two types of FRT programs in different sport performance tasks: variable intensity (VI) and constant intensity (CI) of FRT programs on different strength gains (jump, 1RM, COD, sprint time and FRT variables).

2.3. Hypotheses

In line with previous evidence, a list of hypotheses was established throughout the four studies of this doctoral thesis:

- **Hypotheses 1:** Using lower positions of the conical pulley results in greater concentric and eccentric power output.
- **Hypotheses 2:** Power output will increase when longer rope lengths are used in conical pulley.
- **Hypotheses 3:** The athletes' BM and strength level will allow greater absolute mechanical outputs to be achieved in FRT exercises.
- **Hypotheses 4:** Mechanical outputs will be exercise dependent in FRT.
- **Hypotheses 5:** Specific strength gains (e.g. jump, change of direction - COD, sprint, power and strength ability) will be specific to the force orientation used in FRT.

- **Hypotheses 6:** Varying intensity in an FRT program leads to better medium-term performance adaptations than in a constant intensity program.

3. SUMMARY OF THE METHODS

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3. Summary of the methods

Summary of the methods will be showed in this section in two parts according to the differences in the methodological procedures.

Before starting every research protocol, participants were carefully informed about the benefits and risks, and provided written informed consent in accordance with the Declaration of Helsinki. Participants were informed that they were able to voluntarily withdraw from the study at any moment. Every study was preceded by two familiarization sessions, a protocol proposed by Sabido et al. (2017). All the experimental protocols were approved by the ethics committee of Miguel Hernández University (Code: ADH.DES.RSS.PAV.23).

3.1. Studies 1 and 2

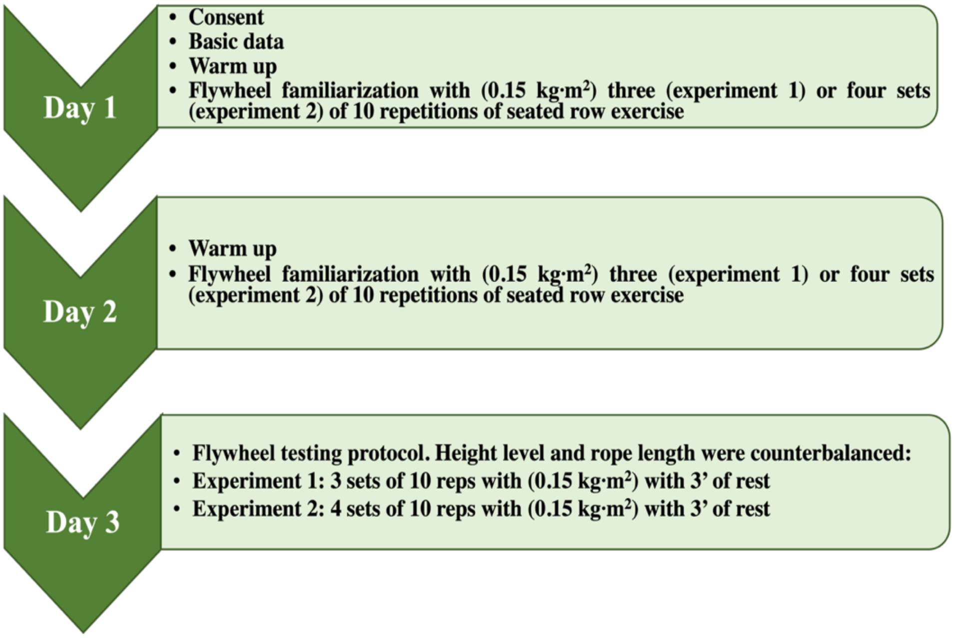
3.1.1. Study 1, experiment 1 and 2: rope length and height level

Participants

For the first experiment, fourteen (n = 14) recreationally trained participants took part in this study: nine men (age: 29.4 ± 7.2 years; weight: 75.8 ± 6.8 kg; height: 1.75 ± 0.02 m) and five women (age: 27.8 ± 5.7 years; weight: 63.6 ± 3.2 kg; height: 1.68 ± 0.03 m). In the second experiment, fifteen (n = 15) recreationally trained males (age: 22.0 ± 1.3 years; weight: 73.5 ± 7.6 kg; height: 1.77 ± 0.04 m) were involved. All participants were recreational athletes from different sports (e.g. soccer, handball, tennis), and reported at least two years of experience in resistance training, including the row exercise. None of them reported previous experience with flywheel exercises. A single researcher conducted all testing sessions, and subjects were scheduled for each session at the same time to minimize experimental variability. Participants were requested to maintain their regular diets and normal hydration levels, refrain from taking nutritional supplements or anti-inflammatory medications, and avoid caffeine intake for 3 hours before each testing session. Additionally, subjects were not allowed to engage in strength training for at least 72 hours prior to the experimental sessions.

Protocols

Two weeks prior to the test, the participants conducted two familiarization sessions (one per week) aiming to learn the protocol and the correct technique to perform the exercise in the conical pulley device (Sabido et al., 2020). Prior to exercise, all participants performed a general warm-up consisting of 5 minutes of jogging and dynamic stretching. Both familiarization and testing sessions included three sets of ten repetitions (first experiment) or four sets (one set per height level in the second experiment) of the seated row exercise using a conical pulley device. Afterwards, a more specific warm-up consisting of a barbell row set of 10 submaximal repetitions, and one set of the seated row exercise with the conical pulley was performed.



Day 1

- Consent
- Basic data
- Warm up
- Flywheel familiarization with (0.15 kg·m^2) three (experiment 1) or four sets (experiment 2) of 10 repetitions of seated row exercise

Day 2

- Warm up
- Flywheel familiarization with (0.15 kg·m^2) three (experiment 1) or four sets (experiment 2) of 10 repetitions of seated row exercise

Day 3

- Flywheel testing protocol. Height level and rope length were counterbalanced:
- Experiment 1: 3 sets of 10 reps with (0.15 kg·m^2) with 3' of rest
- Experiment 2: 4 sets of 10 reps with (0.15 kg·m^2) with 3' of rest

Figure 5. Scheme of the protocol of study 1.

Testing procedure started with participants seated in an adjustable fitness chair leaning the chest on the backrest to facilitate the stabilization, knee joints bent at a 90-degree angle and spine in a neutral position. Execution of the exercise proceeded with pronated grip with full elbow flexion in the CONC phase at maximal velocity and a full extension in the ECC phase, trying to perform a sudden braking action at the end of ECC phase (Sabido et al., 2020). Participants were required to keep the chest in contact with the chair all the time. In experiment 1, within each session, all participants performed one set of 10 repetitions with each of the different rope lengths (1.5, 2.5 and 3.5 m) in a random order, while in experiment 2 each set was performed using a different height level (1, 2, 3 and 4) in the conical pulley (Figure 4). Both protocols were performed with 6 inertial loads (each inertial load weighed 900 grams) resulting in an inertial load of 0.15 kg·m^2. Each height level was spaced 5 cm apart. To prevent potential cumulative fatigue effects, subjects were divided into two groups: an 'ascending order' group (starting from the bottom of the cone at height level 4) and a 'descending order' group (starting from the top of the cone at height level 1) (Sabido et al., 2017). Additionally, both protocols included 3-minute rest intervals between sets.

The conical pulley included an optical receiver (SmartCoach, Europe AB, Stockholm, Sweden) coupled to the device, recording data of each repetition in both the CONC and ECC phase of the movement. Then, a specialized software (SmartCoach Power Encoder, Europe AB, Stockholm, Sweden) was used to process all data, using the variables concentric peak power (PPconc), eccentric peak power (PPecc), and EOL for analysis. A high reliability of this encoder has been previously reported (Sabido et al., 2017). Data included for analysis were the mean of all the repetitions of the set (Sabido et al., 2017).

Statistical analysis

All data were analyzed using the statistical package SPSS 22.0 (SPSS Inc, Chicago, IL, USA). After testing the normality of the data using a Kolmogorov−Smirnov test, a one-way ANOVA was used to analyze differences in the different variables (PPconc, PPecc, and EOL) when using the four different height levels. The same procedure was used for analyzing data regarding rope length. Statistical significance was set at $p < .05$. In addition, the magnitude of the differences was calculated using Cohen's d and interpreted for a recreationally trained sample (1−5 years' experience in resistance training) following Rhea (2004), as $d < 0.35$ (trivial); $d = 0.35-0.8$ (small); $d = 0.8-1.50$ (moderate); $d > 1.5$ (large).

3.1.2. Study 2

Participants

Forty-six (n = 46) recreational athletes took part in this study. Participants had at least one year of experience in resistance training but no experience with flywheel resistance devices. Subjects were assessed for their one-repetition maximum (1RM) and BM, both expressed in kilograms and were subsequently assigned to one of two groups according to the training level based on their 1RM/BM ratio (Haff & Triplett, 2021).

The cutoff for each group was determined using criteria previously described by James et al. (2018), classifying subjects based on their strength level in the back squat exercise. Participants with a ratio of <1.5RM/BM were classified as weak, while those with a ratio of >1.5RM/BM were classified as strong.

Therefore, a stronger group (*n* = 28; 27.42 ± 5 years; 1.74 ± 0.06 m; 72.53 ± 7.96 kg; 1RM = 129.5 ± 16.94; 1RM/BM = 1.79 ± 0.15) and a weaker group (*n* = 18; 26.1 ± 5.23 years; 1.77 ± 0.08 m; 78.22 ± 15.34 kg; 1RM = 115.16 ± 28.46 kg; 1RM/BM = 1.24 ± 0.13) were identified.

Protocols

Participants came to the laboratory on three separate occasions (72 h of recovery between sessions). On the first day, descriptive (e.g., age, training level) and anthropometric data were recorded for each participant. After that, the 1RM back squat and first flywheel familiarization session were completed (Sabido et al., 2017). On the second day, the second flywheel familiarization protocol took place. On the last day, a randomized flywheel exercise protocol was performed. The variables used for data analysis were peak concentric power (PPconc), peak eccentric power (PPecc), and the eccentric/concentric ratio (Asencio et al., 2024). Their relationship with the 1RM/ BM ratio was calculated for squat and split squat exercises.

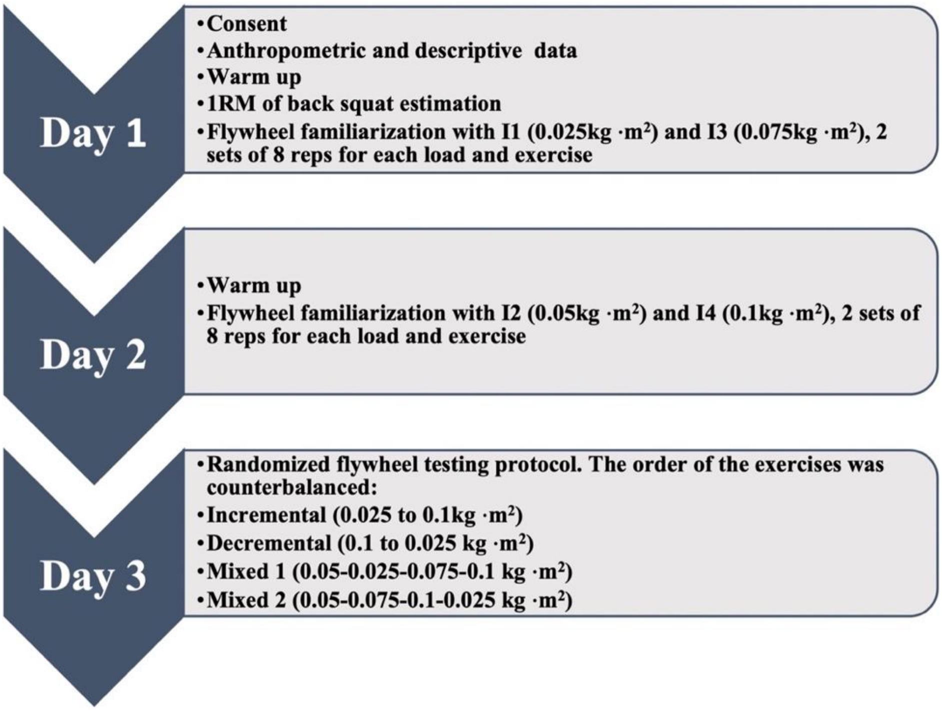


Figure 6. Scheme of the protocol of study 2.

On day one, subjects performed a 1RM back squat exercise measured by a linear encoder (T-Force System, Ergotech, Murcia, Spain) with specific software application to calculate kinetic and kinematic variables. The protocol described by Loturco et al. (2016) was followed for the 1RM estimation, which consisted of starting in fully extended position with the barbell resting on scapular level of the upper back, followed by a parallel squat. Each participant descended until their thighs were parallel to the ground and then ascended to the upright position. A load of 50% of participant's BM was chosen to start the test, the load gradually increased until three repetitions as fast as possible was performed with a mean propulsive velocity being lower than $< 0.5\ m \cdot s^{-1}$ to automatically estimate the 1RM of the athletes. The rest interval between sets was 4 minutes. The 1RM was estimated through movement velocity, as previously described (Lorutco et al., 2016).

During the last testing day, subjects completed trial with a randomized and counterbalanced exercise and load protocol (Incremental, Decremental, Mixed 1, Mixed 2), doing one maximum set of 10 repetitions with the addition of two initial repetitions needed to initiate the flywheel movement (Sabido et al., 2019). The inertial loads used during the squat and split squat exercises were 0.025 (I1), 0.05 (I2), 0.075 (I3) and 0.1 $kg \cdot m^2$ (I4)

(Asencio et al., 2024). Following each set, as per Sabido et al. (2018), participants rested for two minutes (for I1 and I2) or three minutes (for I3 and I4). During each repetition, both the concentric and eccentric power were recorded using an encoder and subsequently analyzed (SmartCoach Power Encoder, Europe AB, Stockholm, Sweden).

Statistical analysis

Statistical analyses were performed using the R-Studio program (4.0.2 version). By using the bootstrapping technique with 1000 randomly bootstrapped samples, a reliable estimate of 95% was determined for the confidence interval. The data were shown as the average of the mean of eight repetitions for each set (Sabido et al., 2018). Values were compared between the different inertial loads and exercises through a two-factor ANOVA test (different inertias and training levels based on the 1RM/BM ratio). If necessary, the Bonferroni post hoc test was carried out for pairwise comparisons. The level of statistical significance was set at $p < 0.05$. To assess the magnitude of the changes, a Cohen effect size (ES) calculation was performed, interpreted as trivial (< 0.2), small (0.2–0.5), moderate (0.5–0.8) and large (> 0.8) (Rhea, 2004).

3.2. Studies 3 and 4

As studies 3 and 4 share similarities in methods, some sections will be presented jointly, highlighting only the areas where differences exist.

Participants

For *study 3*, thirty-three (n = 33) male recreational athletes (age = 23.40 ± 5.34 years; height = 1.77 ± 0.07 m; body mass = 75.35 ± 13.96 kg) from different intermittent sports (e.g., football, futsal, tennis, and basketball) took part in the study. Despite all participants having a minimum of 12 years of experience in their respective sports, none were familiar with flywheel resistance training. All participants were engaged in sport-specific on-court training three days per week, but they were not currently participating in any strength program during the study period. According to the aim of the study, participants were stratified based on their 1RM/ body mass strength and randomly assigned to one of the three different flywheel resistance training programs, using these vertical-directed exercises (VR group, n = 11; 22.6 ± 4.0 years; 1.79 ± 0.09 m; 75.5 ± 14.1 kg), horizontal-directed exercises (HR group, n = 8; 22.0 ± 4.1 years; 1.76 ± 0.05 m; 74.9 ± 11.4 kg) or a mix of vertical- and horizontal-directed exercises (MIX group, n = 10; 24.9 ± 6.3 years; 1.77 ± 0.09 m; 75.6 ± 16.8 kg). Initially, all groups included 11 participants, but during the study, a total of four participants dropped out, being three from the HR group and one from the MIX group. These drop outs were not related to injuries nor to reasons related to the study.

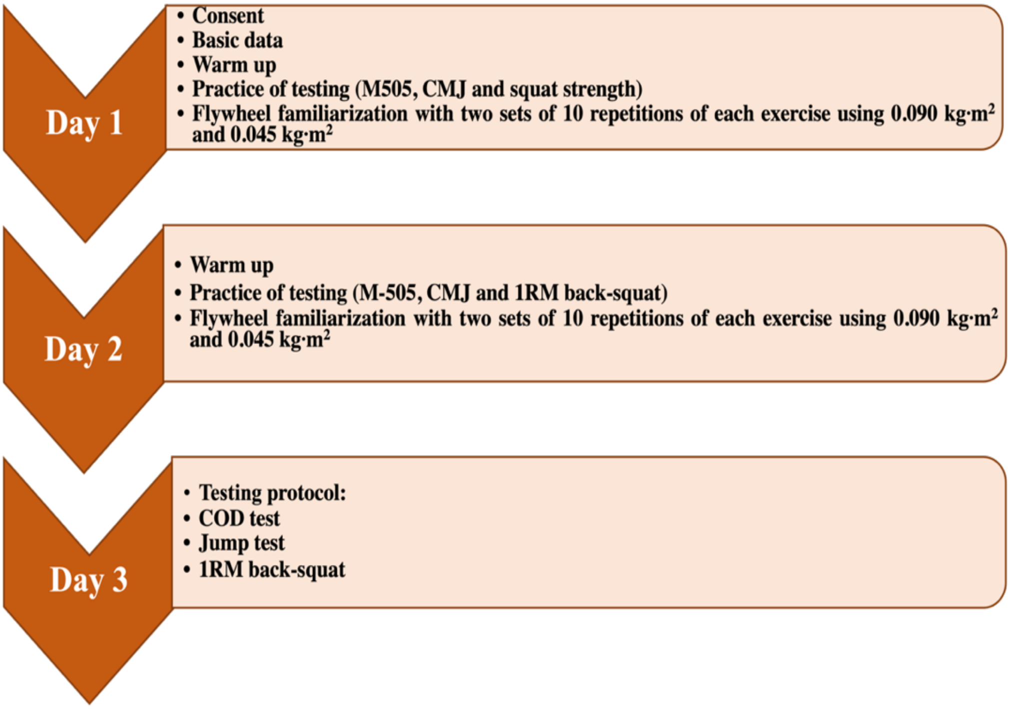


Figure 7. Scheme of the pre-test of study 3.

In *study 4,* seventeen (n = 17) amateur footballers with at least two years of experience in resistance training took part in this study. Participants were assigned to one of two homogeneous groups according to demarcation and strength level based on their 1RM/body mass. The VI group (n = 8; age = 22.00 ± 5.71 years; height = 1.82 ± 0.08 m; body mass = 76.20± 6.40 kg; 1RM = 132.48 ± 18.90; ratio 1RM/body mass = 1.74 ± 0.29) trained with decreasing inertial load every four training sessions (0.12 kg·m^2; 0.10 kg·m^2; 0.08 kg·m^2) and the CI group (*n* = 9; age = 22.9 ± 7.2 years; height = 1.80 ± 0.04 m; body mass = 75.66 ± 6.13 kg; 1RM 130.41± 19.87 kg; ratio 1RM/body mass 1.80 ± 0.04) trained with 0.08 kg·m^2 during the entire training period.

Protocols

Jumping performance test

To assess jump ability, a bilateral CMJ without arm swing were performed. Participants performed the jumps in a contact platform (Chronojump Boscosystem). The procedure started in a standing position with their hands in their hips; they flexed their knees using a self- selected depth and then jumped as high as possible. In *study 3*, each participant performed five maximal CMJs interspersed with 45 s of passive recovery, while in *study 4*, three attempts were assessed and the best trial was used for analysis. The best and worst of the trials were eliminated, and the three remaining jumps were averaged.

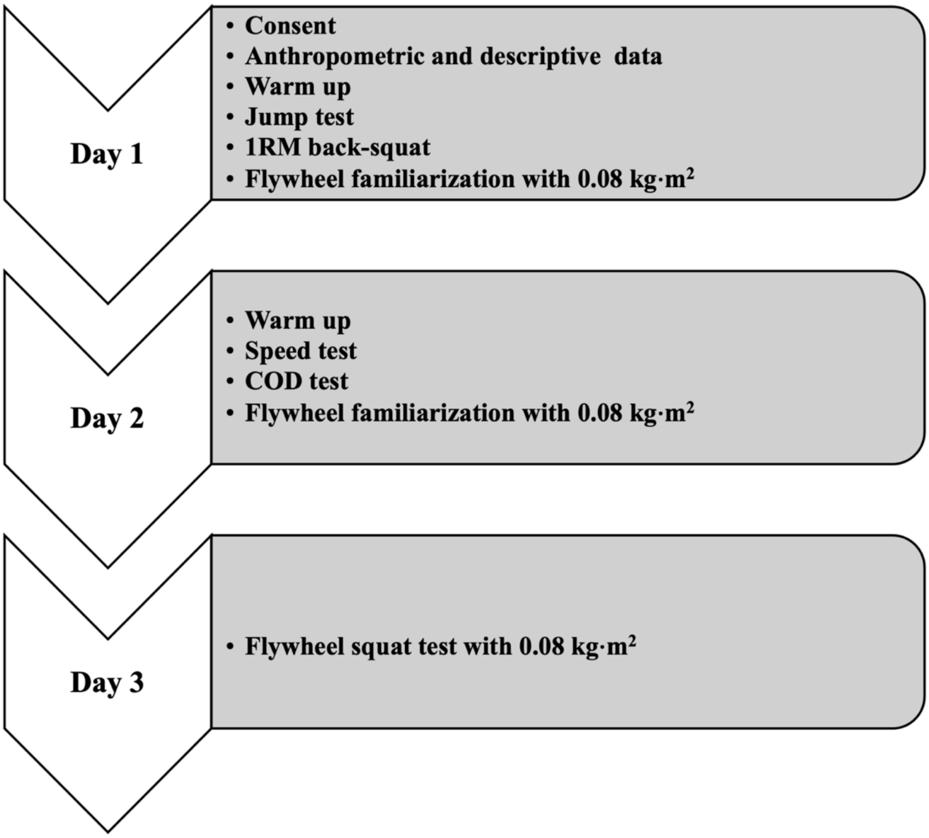


Figure 8. Scheme of the pre-test of study 4.

COD performance test

The ability of participants to perform maximal 180° COD over 5 m was evaluated using a modified version (stationary start) of the 505 test (M-505) (Raya-González et al., 2021). Participants started with their preferred foot behind the starting line in a standing position, followed by accelerating forward at maximal effort until reaching a line placed at 5 m. Two trials pivoting on both dominant (i.e., preferred kicking leg) and non-dominant leg were completed, and the fastest time recorded by means of a contact platform (*study 3*) (Asencio et al., 2022) (Chronojump Boscosystem, Barcelona, Spain) and timing gates (Microgate, Bolzano, Italy) (*study 4*) (Asencio et al., 2024) were positioned at the starting and finishing points. Two minutes of rest was allowed between trials. Tests started on the "Go" command from a standing position up the platform (*study 3*), or with the front foot 0.2 m from the photocell beam (*study 4*).

Maximum dynamic strength test

The 1RM test was carried out using a linear position transducer (Chronojump Boscosystem), which recorded the bar position with an analogue-to-digital conversion rate of 1000 Hz. A specialized software application (Chronojump Boscosystem version 1.8.1) and (T-Force System, Ergotech, Murcia, Spain) automatically calculated the relevant kinetic and kinematic parameters for studies 3 and 4 respectively (Pérez-Castilla et al., 2019). In order to estimate 1RM, participants began with a shoulder-width stance and the barbell positioned on the upper back near the acromion level, with knees and hips in full extension. Each participant descended until their thighs were parallel to the ground and then ascended to the standing position. Initially, participants lifted a load equal to 50% of their body mass. Subsequently, the load was progressively increased until the mean propulsive velocity dropped below 0.5 $m \cdot s^{-1}$.Using this submaximal load, participants performed three maximal-intended repetitions and the specialized software of the linear position transducer automatically estimated the 1RM. Several studies have supported the use of movement velocity for 1RM estimation (Pérez-Castilla et al., 2019). Rest interval between sets was between 3 and 4 minutes.

Sprint ability

To assess speed ability, the 10-m sprint and 30-m sprint were performed on a grass soccer field. The test started 1 m behind the start line in a starting position with the body leaned forward. Timing gates (Microgate, Bolzano, Italy) were placed at the start (0 m), middle (10 m) and end (30 m), with reflectors at 1 m height (Tous-Fajardo et al., 2016). Participants were directed to perform sprint at maximum capacity for all the distance . Each participant completed three attempts with a 2-minute passive recovery period between each (Asencio et al., 2024). The best score from these attempts was utilized for the analyses.

FRT variables

The variables used for data analysis were peak concentric power (PPcon), peak eccentric power (PPecc) and the eccentric overload (EOL) ratio. On the last testing day, participants completed a flywheel squat test with the flywheel device (VersaPulley, Iberian Sportech, Seville, Spain), carrying out a maximum set of eight repetitions, with an additional two initial repetitions needed to build momentum. The inertial load used during the test was 0.08 $kg \cdot m^2$ (Asencio et al., 2024). Participants performed two sets to warm up with a 2-min rest interval, a protocol recommended by Sabido et al. (2017). During each repetition the concentric and eccentric power (and their ratio) were recorded using a linear encoder and subsequently analyzed (SmartCoach Power Encoder, Europe AB, Stockholm, Sweden).

Training programs

- **Study 3**

One week after the pre-test, participants started a 4-week flywheel resistance training intervention using a conical pulley device (VersaPulley, Iberian Sportech, Sevilla, Spain).

Each group performed two training sessions per week with equal taining volume between groups (i.e., two exercises, three sets of eight repetitions per session). After a standardized warm-up, each group performed eight trials of the M-505 test followed by 30 seconds rest between trials. After M-505 trials, subjects did three sets and four repetitions of SJ (weeks 1 and 2) and CMJ (weeks 3 and 4) with the 30% of 1RM (Asencio et al., 2022). Training was followed by a flywheel training session with 0.090 kg·m^2 of inertia during the first two weeks, and 0.045 kg·m^2 during weeks three and four. To maximize movement velocity, the widest part of the conical pulley was selected for the strap rewind height (Sabido et al., 2020). This programming approach was used to combine different inertial loads with the goal of improve athletic performance (Sabido et al., 2020; Beato et al., 2021). The FRT programs varied depending on the exercises' force direction, focusing either on horizontal-directed force (HR group), vertical-directed force (VR group), or a combination of both (MIX group). During all training sessions participants were fully encouraged to perform the concentric action as fast as possible and to delay the braking phase to the last part of the eccentric action, which facilitate the achievement of eccentric overload.

- **Study 4**

This experimental study was performed during the seven pre-season week period (see Table 2). Performance testing took place during weeks 1 and 7. Once testing and familiarization finished, participants were divided into two groups, each with differente insity distribution (VI and CI). Participant in the VI group had inertial load changins grom higher to lower, while the CI group maintained the same inertial load throughout each training session. In regards to the density and the total volume of the training sessions, both groups were equal (Asencion et al., 2024).

On week one, three testing sessions took place, taking into consideration a total of 72 h of recovery between sessions. Descriptive (e.g. age, training level) and anthropometric data were recorded on day one for all participants followed by jump tests and a 1RM in back squat test. Day one finalized with a flywheel familiarization protocol (Sabido et al., 2020). On day two, participants performed speed and COD test, followed by the another flywheel familiarization protocol. The third testing session consisted of performing a flywheel squat test.

After pretesting in week one, the flywheel training program started. Both groups trained twice per week. Both groups had equal total training volume. To maximize movement velocity the widest part of the conical pulley was chosen (Sabido et al., 2020) (see Table 1). The training program started with a general warm-up, followed by two flywheel exercises with different force vectors (vertical squat and horizontal lunge) (Asencio et al., 2024), and a general soccer injuty prevention program (e.g. core stability, balance and proprioceptive and hamstring eccentric exercises). The flywheel exercises required two intial repetitions to build inertia momentum. Participant were instructed to perform each repetition as fast as possible and to delay the braking action for the last third of the eccentric phase (Sabido et al., 2017). Rest intervals were standardized at 2 min, as recommended by Sabido et al. (2018). The training protocols showed training intensity variations, focusing on either a convential training block from high to low loads (G1) or constant load (G2) approaches (see Table 1). After week 6, participants performed the posttest procedure.

Statistical analysis

All statistical analysis were performed using the SPSS statistical package version 25.0 (IBM, New York, NY, USA). Data normality were confirmed using the Kolmogorov-Smirnov (*study 3*) and Shapiro-Wilk (*study 4*) test. Furthermore, in *study 4* Levene's test for homogeneity of variances was employed to assess the equality of variances across groups or conditions and to assess the assumption of sphericity in repeated measures or within subjects, Mauchly's sphericity test was employed. The effectiveness of each program (VR, HR, and MIX) for *study 3* was assessed using a 3 (VR, HR, and MIX)×2 (pre and post) mixed ANOVA, while mixed ANOVA (time per group) were used to compare VI and CI for *study 4*. Due to small sample size during *study 4*, individual data analysis was presented using 2*SEM (standard error of the mean) to establish individual changes between responders and non-responders athletes. If needed, a Bonferroni post hoc test was used for pairwise comparisons. Statistical significance was set at $p < 0.05$. To assess the magnitude of the changes, Cohen's d effect size (ES) calculation was performed, with interpretations as trivial (< 0.2), small (0.2–0.5), moderate (0.5–0.8) and large (> 0.8) (Ferguson, 2009).

4. SUMMARY OF THE RESULTS

Imagen de fuente propia

4. Summary of the results

4.1. Influence of the strap rewind height during a conical pulley exercise

Experiment 1: Rope length

Non-significant differences were found in PPconc, PPecc and EOL for any variable. Nevertheless, there was a trend for significantly higher PPecc values as the rope length increases (small ES). Similarly, differences in EOL were close to significance, comparing 1.5 m length (1.18 ± 0.20) with 3.5 m length (1.26 ± 0.19).

Experiment 2: Height level of strap rewind

The highest position of the pulley, corresponding to level 1, resulted in the lowest PPconc values compared to lower pulley positions (levels 2, 3, and 4). Conversely, PPconc was significantly higher at the lowest position (level 4) compared to levels 3 and 2, with small and moderate effect sizes.

In the highest position (level 1), PPecc values were lower compared with levels 3 and 4 with small effect sizes. In addition, significantly higher values of PPecc were found when using level 4 compared with level 2 (766 ± 258W vs 649 ± 256W).

Conversely, for EOL, the higher values were found in level 1, being significantly greater than those in levels 2, 3 and 4 with small and moderate effect sizes. In addition, EOL values in level 2 were significantly higher than in level 4 (1.11 ± 0.16 vs 1.01 ± 0.13).

4.2. Analysis of concentric and eccentric power in flywheel exercises depending on the subjects' strength level and body mass

There were differences between inertial loads for absolute EOL inertial loads in weaker participants, but not in stronger participants in squat exercise. These differences are not influenced by BM. Similar results were found for EOL/BM between inertial loads during the split squat exercise. In addition, for the absolute power values in the CONC phase, there were differences between inertias in both groups, achieving higher values with lower inertias.

We found that both the stronger and the weaker group were influenced by inertial loads in both exercises for the CONC phase related to BM. However, stronger participants showed higher concentric ratios in I1 and I2 in comparison with the weaker group. In the ECC phase, moreover, there were significant differences between the stronger and weaker groups in I2 in the split squat (non-dominant) and in I1 and I2 in the squat exercises. No meaningful interactions between inertial loads, exercise and training level were found.

4.3. Effects of flywheel resistance training using horizontal vs vertical exercises

The duration of the training had a positive effect on improving all performance variables in every group. Consequently, no interaction effect was found for the effect of the training on the experimental groups in 1RM, CMJ, M-505D and M-505-ND. For the 1RM squat, significant improvements were found in the vertical and mixed groups. All groups showed significant increases in CMJ height. Regarding M-505 with the dominant leg, both the vertical and the mixed groups showed significant decreases in M-505 time. For the M-505 with the non-dominant leg all groups showed significant decreases in M-505 time.

Vertical and mixed groups showed greater improvements in 1RM (+7,6 and 9,5 kg respectively), in contrast with the 3,5 kg of the horizontal group. For M-505ND the horizontal group showed greater performance increases (-0,36 seconds) of small and moderate magnitude than the vertical and the mixed group respectively. In addition, horizontal group showed slightly greater improvements (of small magnitude) than the vertical and mixed groups.

4.4. Comparison of two types of flywheel training programs on soccer players' performance

Training had a positive effect in some performance variables in every group, with pre- to post- changes in performance variables. Both groups showed no changes in CMJ height, M505-ND or 30-m sprint time. Furthermore, both groups showed significant decreases in M505D. However, in the 10-m sprint, the constant intensity group showed significant improvements. There were also significant improvements in the 1RM values for both groups. Finally, for the flywheel performance variables, variable and constant intensity groups showed increases in PPconc (9.42% and 10.50%) and PPecc (13.80% and 15.60%) respectively.

5. GENERAL DISCUSSION

Imagen de fuente propia

5. Summary of the discussions

5.1. Influence of the strap rewind height position during a conical pulley exercise

The present study showed a significant influence of strap rewind height on all the variables measured (PPconc, PPecc and EOL). Greater PPconc values have been reached with the lowest position. Furthermore, a linear relationship was observed between the change in the pulley height and PPconc, increasing by approximately 15% as the pulley was placed in the next (wider and lower) position. Similarly, PPecc also increased when lower heights of the pulley were used. Nevertheless, the slope of the changes when modifying the height was less pronounced than in the study of Vázquez-Guerrero et al. (2016). This almost linear relationship between changes in the height and power output modifications may be used by coaches to prescribe FRT accurately. Thus, by modifying the height at which the pulley is positioned and using wider cone diameters, athletes can perform faster movements with higher power outputs. As Sabido et al. (2019) reported, this fact may have consequences for dynamic athletic performance (i.e. sprint and COD abilities) when using flywheel devices configured to allow higher velocities and PP values (i.e., low inertial loads) compared with lower velocities (i.e., high inertial loads).

In contrast with PP values, EOL was significantly greater when using higher due to the lower movement velocities reached. This condition allowed athletes to perform a longer muscle action, allowing greater force output. Using higher positioning of the pulley entails similar responses as increasing the inertial load, causing lower PP values but increasing EOL (Sabido et al., 2018). Although greater PP output could be useful for more functional exercises, greater EOL values may be a key factor for muscular adaptations. The ability to produce higher levels of ECC force at long muscle lengths (as when using flywheel devices) has been linked to greater hypertrophy (Noorkoiv et al., 2014). Consequently, it can be suggested that the use of higher positions in the conical pulley may be a more effective option when optimizing structural adaptations. Further, a review of flywheel training has shown that increases in force are higher when greater EOL values have been reached (Nuñez-Sanchez and Saez de Villarreal, 2017). Thus, when aiming to develop muscular strength, the use of higher positions of the conical pulley could be a better choice.

5.2. Analysis of concentric and eccentric power in flywheel exercises depending on the subjects' strength level and body mass

Results showed greater PPconc and PPecc values for squat and split squat exercises with lower inertial loads. These findings agree with previous studies that tested other exercises (i.e., squat, romanian deadlift, leg extension and leg curl) (Sabido et al., 2018; Muñoz-Lopez et al., 2023; O'brien et al., 2022; Martínez-Aranda et al., 2017; Piqueras-Sanchiz et al., 2020). However, no differences between inertial loads in PPconc were reported in other studies (De Keijzer et al., 2022; Maroto-Izquierdo et al., 2021). McErlain-

Naylor and Beato (2021) found a similar pattern for velocity and PP variables in a group of subjects with lower strength. However, the patterns of PPconc and PPecc were very different for the "stronger" group concerning the study of McErlain-Naylor and Beato, possibly due to the athletes' strength level of this study. On the other hand, other authors (de Keijzer et al., 2022; Suarez-Arrones et al., 2020; Martínez-Aranda et al., 2017) tested unilateral open-chain movements (i.e., knee flexion and hip extension), revealing different behaviour of power-inertia profile. It is important to indicate that arm positioning during a given movement (e.g., perpendicular in the study of Keijzer et al. or located directly in the flywheel device in a study by Suarez-Arrones et al. (2020) and the possibility of stabilizing the action can modify power values and explain the differences between power profiles.

Regarding EOL, the values increased as inertial load increased in bilateral squat (specially with weaker athletes) and unilateral split squat exercises. The findings align with previous research showing EOL increases when the load is greater in several exercises (i.e., squat, romanian deadlift and leg curl) (Sabido et al., 2018; McErlain-Naylor & Beato, 2021; O'Brien et al., 2022; Piqueras-Sanchiz et al., 2020). Similar research by Muñoz-López et al. (2023) found a trend for EOL increases with low (0.025 kg·m^2) inertial loads compared to high inertial loads (0.125 kg·m^2). In contrast to these findings, McErlain-Naylor and Beato (2021) reported different results even though they used a half-squat exercise. These differences are probably due to the athletes' different strength abilities, but these observations were not discussed in detail.

As previously stated, all three analyzed variables (EOL, PPcon and PPecc) showed a similar pattern in the squat and split squat exercises. EOL tended to increase with the inertial loads, whereas PPcon and PPecc tended to decrease with the inertial loads. However, three key observations should be mentioned. Firstly, the stronger group did not report any significant difference in EOL using any load during the squat exercise. Thus, stronger participants could train with any load to obtain EOL, while weaker participants should preferentially train with higher inertial loads (0.075 or 0.100 kg·m^2). Secondly, PPecc achieved in the split squat with the non-dominant limb did not differ between inertial loads. Therefore, practitioners who want to employ unilateral movement in their training protocol should perform long familiarization periods with the non-dominant leg, as previously recommended (Sabido et al., 2018). Lastly, in contrast with Piqueras et al.'s (2020) results, when the training goal is to maximize PPecc, a different profile could be observed on the basis of the subjects' training level. In our study, participants with similar previous experiences displayed different EOL profiles according to their relative strength (1RM squat/BM). Thus, relative strength could be a key variable for programming FRT because the strength level can influence velocity improvement (James et al., 2018).

5.3. Effects of flywheel resistance training using horizontal vs vertical exercises

The better results found of vertical exercises in FRT are in line with Contreras et al. (2017), who reported that a vertical exercise (e.g., squat) was possibly more effective in increasing 1RM in the squat exercise than horizontal (e.g., hip thrust). These results are of significant practical application, as increases in 1RM squat during the pre-season period have been previously linked to improvements in sprint performance (Comfort et al., 2012). Although some part of these improvements could be attributed to the athlete´s training status (e.g., recreational players), it should be highlighted that previous research using flywheel devices used longer training programs (e.g., 5–12 weeks). Conversely, the present study demonstrated improvements after a 4-week training program, a duration which matches the habitual volume of the team sports pre-season.

The improvements in CMJ found in the three groups were almost identical, with moderate ES magnitude. This finding is in line with previous studies reporting similar increases in vertical jump performance after plyometric training using either vertical or horizontal exercises (Manouras et al., 2016) or mixed vertical and horizontal exercises in recreational athletes practicing intermittent sports (Ramirez-Campillo et al., 2015). Moran et al. (2021) confirmed this idea in a recent meta-analysis in which force direction in plyometric exercises had no relevance to improving CMJ. While Contreras et al. (2017) suggested vertical resistance exercise as possibly most appropriate to improve vertical jump performance, other authors have shown the efficacy of horizontal exercises (e.g., hip thrust) in improving CMJ performance (Fitzpatrick et al., 2019). In addition, Gonzalo-Skok et al. (2017) reported similar significant improvements in CMJ performance after a flywheel training intervention in both vertical and multidirectional training groups. It can be suggested that the exercises considered horizontal induce a positive effect on vertical jump performance, probably through their similar movement patterns to the CMJ. Thus, it is possible to consider the selection of either horizontal, vertical, or mixed FRT exercises as suitable when aiming to improve CMJ performance in recreational athletes.

In agreement with the previous research (Manouras et al., 2016; Gonzalo-Skok et al., 2019), all groups showed significant reductions (moderate to high ES) in M505 completion time. Despite the fact that some authors have suggested that exercises with different vectors may lead to distinct performance adaptations, the current study demonstrated that all training groups improved COD performance to a similar degree. Although the magnitude of changes in the HR group was slightly higher compared with both VR and MIX groups, these changes did not reach statistical significance. This observation is in line with previous research using plyometric (Manouras et al., 2016; Gonzalo-Skok et al., 2019) and flywheel training (Raya-González et al., 2021), where similar improvements in COD performance were found in both vertical and horizontal groups. Improvements in M505 performance in the current study (7–10%) were higher than the improvements reported by Manouras et al. (2016) (3–4%) and Gonzalo-Skok et al. (2019) (3%). The magnitude of improvements in different studies could be explained by the athlete's strength level. Again, the results of the present study support the inclusion of FRT when aiming to improve COD ability.

5.4. Effects of variable intensity and constant intensity flywheel resistance training programs on specific soccer players' performance

Our results showed significant improvements in 1RM variable, which is linked with higher specific soccer performance (Requena et al., 2009; Comfort et al., 2014) and its influence on individual players' performance (Owen et al., 2015; Wing et al., 2020). The benefits of FRT obtained in our study were similar to those reported in previous research (Fernández-Gonzalo et al., 2014; Sabido et al., 2017; Sagelv et al., 2020). Individual outcomes of short-distance sprint performance surpassing twice the value of SEM for the 10-m sprint test and flywheel squat power values indicate substantial performance changes according to the previous statistical analysis. These results agree with the previous studies (Núñez et al., 2018; Suarez-Arrones et al., 2018; Coratella et al., 2019; Sagelv et al., 2020; Raya-González et al., 2021). Although the trend to improve the 10-m sprint test was observed in both groups, only the CI group obtained a significant difference, probably due to the use of lower inertial loads. According to Sabido et al. (2018), lower inertial loads are a better option for eliciting high concentric PP values, and, according to our FRT results, a low load where high power is produced can be the best choice to optimize short-sprint ability. It can be the reason for the greater PPcon and PPecc in the CI group compared to the VI group (10.50% vs 9.42% and 15.60 vs 13.58 in PPcon and PPecc, respectively). Accordingly, *study 3* of this thesis has suggested that lower inertial loads could be optimal for trained subjects to obtain the maximal power values in the CONC and ECC phases during squat exercises in FRT.

Studies on FRT have reported that this methodology can be very useful for improving jump ability, COD and sprint tasks in football players (Gonzalo-Skok et al., 2017; Coratella et al., 2019; Fiorilli et al., 2020). Nevertheless, our results show that the CMJ, COD and 30-m sprint did not improve in any of the groups after ten sessions of FRT, and even worse values were found for M505-D. These results are in line with the individual SEM analysis, showing a similar or high number of non-responders for several tests. Two reasons could be attributed to explain the results obtained in our study: in the first place, the absence of complementary training (Pecci et al., 2022) to improve specific technique skills, and secondly, neuromuscular fatigue due to the high number of friendly matches and consequently the recovery inability could also influence these results (Hernández-Davó et al., 2022).

6. CONCLUSIONS AND PRACTICAL APPLICATIONS

Imagen de fuente propia

6. Conclusions and practical applications of the thesis

6.1. General conclusions

This doctoral thesis is composed of four studies. *Studies 1* and *2* analyze the mechanical variables of FRT and the impact of athletes' characteristics such as body mass (BM) and strength level on power outputs and two experimental studies. *Studies 3* and *4* to explore the influence of specific training variables (e.g., force direction and intensities' variation) in sport-specific tasks.

The main conclusions of this thesis are:

Study 1

1) Increasing the rope length during an exercise, avoid slightly greater PPecc and EOL values but not with significant differences.

2) Nevertheless, the factor explaining greater PPconc, PPecc and EOL is the height level used in the conic pulley. The bottom positions of the cone (greater diameters) allow for greater PPconc and PPecc, while the top positions (smaller diameters) produce greater EOL values.

3) FRT exercises should be prescribed in agreement with the primary goal of the training session (e.g., maximizing power output or achieving greater EOL values). In addition, conical pulley exercises should be performed using a higher position to maximize force and hypertrophy adaptations. However, in training periods close to competitions, lower cone positions would achieve greater peak power output.

Study 2

4) EOL, PPcon and PPecc showed a similar pattern in the squat and split squat exercises. EOL tended to increase with the inertial loads, whereas PPcon and PPecc tended to decrease with the inertial loads.

5) There are two exceptions that should be mentioned. First, stronger athletes did not report any significant difference in EOL using any load during the squat exercise. Secondly, no differences between the inertial loads were observed for PPecc in the split squat with the non-dominant limb. Thus, it can be hypothesized that stronger participants can train with any load to obtain an EOL, while weaker participants should preferentially train with higher inertial loads (0.075 or 0.100 kg·m^2) to obtain greater EOL values in the squat exercise. Nevertheless, when the main goal of the protocol is to maximize PPecc, a different profile could be observed on the basis of the subjects' training level. The "weaker" group obtained similar outputs using different inertial loads, which could be due to the difficulty

of subjects breaking the action during the ECC phase.

6) Therefore, in line with the last point, strength and conditioning coaches who want to employ unilateral movements in their training protocol should perform long familiarization periods with the non-dominant leg.

7) In our study, participants with different strength level showcased different EOL profiles according to their relative strength (1RM squat/BM). Thus, relative strength is a key variable for programming FRT because the strength level can influence velocity improvement. It is recommended that the practitioner perform a test to understand the inertial load–power profile (CONC, ECC and EOL) for each exercise and also consider the user's strength level for selection of the inertial load as well as for the exercise to use in training.

Study 3

8) FRT, in spite of the different loading conditions (e.g., vertical or horizontal exercises) is highly effective in improving 1RM squat strength, CMJ performance and COD ability.

9) Strength and conditioning coaches should be aware that, VR and MIX loading conditions are useful to improve 1RM squat. Thus the inclusion of vertical-directed exercises is recommended when aiming to optimize strength levels.

10) There were no apparent differences between either horizontal-, vertical-directed, or a combination of horizontal and vertical-directed exercises in promoting improvements in CMJ and COD performance.

11) Improvements in jumping and COD performance were visible after a short-term (i.e., four weeks) training intervention. Due to the congested calendar of most team-sports, with pre-season periods of approximately 4 weeks, this study highlights FRT as a powerful stimulus to achieve performance adaptations in brief periods.

Study 4

12) Both training (VI and CI) are useful to improve strength levels. In contrast, constant inertia seems better choice to improve the 10-m sprint

13) In addition, there are other performance tasks (i.e. CMJ or COD) that need another type of training load (e.g. lower intensity and volume or complementary training) to maximize performance

14) Strength and conditioning coaches of soccer players with high 1RM/body mass ratio should individualize FRT programs using CI (medium and lower inertias) and perform complementary training in promoting specific soccer performance improvements.

The findings of this doctoral thesis highlight how different exercise and participant characteristics affected power outputs and EOL values in FRT and their application in FRT programs. The *studies 1* and *2* included in this thesis show the importance of FRT individualization based on strap rewind, height level, type of exercise, inertial loads, athlete's characteristics and training level. In line with this, *studies 3* and *4* collected in this thesis show the importance of training programming based on athlete's performance needings using different force directions and optimal intensity. FRT must be individualized not only depending on the type of exercise and device to be used, but also taking into account the training level and individual performance needs of each athlete.

6.2. Conclusiones generales

Esta tesis doctoral está compuesta por cuatro estudios. Los *estudios 1* y *2* analizan las variables del ejercicio y las características de los atletas (como la masa corporal y el nivel de fuerza) sobre la producción de potencia en diferentes dispositivos isoinerciales. En segundo lugar, los *estudios 3* y *4* tratan de analizar la influencia de variables como la prescripción de intensidad y la orientación de la fuerza en diferentes programas de entrenamiento para mejorar el rendimiento deportivo.

Las principales conclusiones de esta tesis doctoral son:

Estudio 1

1) Aumentando la longitud de la cuerda durante un ejercicio de polea cónica, se alcanzan mayores valores de pico de potencia excéntrico así como sobrecarga excéntrica ligeramente mayores, aunque sin diferencias significativas.

2) El nivel de altura utilizado en la polea cónica es el factor que más influye en los picos de potencia, tanto excéntricos concéntricos así como en la sobrecarga excéntrica. Las posiciones inferiores del cono (diámetros grandes) permiten que se produzcan mayores picos de potencia, mientras que las posiciones superiores (diámetros pequeños) causaron mayores valores de sobrecarga excéntrica.

3) Se debe considerar que los ejercicios ejecutados en la polea cónica deben realizarse utilizando una posición más alta para maximizar la fuerza y las adaptaciones de

hipertróficas. Sin embargo, en periodos de entrenamiento cercanos a las competiciones, las posiciones más bajas del cono lograrían una mayor producción de potencia máxima.

Estudio 2

4) Los valores de sobrecarga excéntrica y los picos de potencia para la fase concéntrica y excéntrica del movimiento con dispositivos isoinerciales mostraron un patrón similar en los ejercicios de sentadilla y sentadilla split. La sobrecarga excéntrica tiende a aumentar con el incremento de la inercia utilizada, mientras que la potencia se ve favorecida con las inercias menores.

5) Los atletas más fuertes pueden alcanzar sobrecarga excéntrica usando cualquier carga durante el ejercicio de sentadilla. Esto sugiere que las consideraciones para alcanzar sobrecarga excéntrica durante el entrenamiento son distintas para los atletas dependiendo de su nivel de entrenamiento, teniendo en cuenta que los participantes más débiles deberían entrenar preferentemente con cargas inerciales más altas (0,075 o 0,100 $kg \cdot m^2$) para conseguir este objetivo en el ejercicio de sentadilla.

6) El pico de potencia excéntrico en la sentadilla split con la extremidad no dominante no mostró diferencias entre las cargas inerciales en los atletas con menor nivel de entrenamiento. Por lo tanto, cuando el objetivo del protocolo es maximizar el valor de potencia en la fase de frenado, se debe tener en cuenta que los atletas con menor nivel de fuerza obtuvieron resultados similares utilizando diferentes cargas inerciales, lo que podría deberse a la dificultad de los sujetos para frenar durante la fase excéntrica.

7) En línea con el punto anterior, los entrenadores de fuerza y acondicionamiento que quieran emplear el movimiento unilateral (especialmente con atletas que tengan un bajo nivel de entrenamiento) en su protocolo de entrenamiento deben realizar largos períodos de familiarización con la pierna no dominante.

8) Los atletas pueden mostrar diferentes perfiles de sobrecarga excéntrica según su fuerza relativa en el ejercicio de sentadilla. Por lo tanto, para programar el entrenamiento con dispositivos isoinerciales y dada la influencia de la velocidad del volante en los niveles de potencia producidos, se recomienda obtener el perfil de carga-potencia para cada ejercicio y seleccionar la carga inercial en función del nivel de fuerza del deportista, así como el ejercicio a utilizar en el entrenamiento .

Estudio 3

9) El entrenamiento con flywheel es efectivo para mejorar la fuerza máxima en sentadilla, el salto vertical y el cambio de dirección independientemente de la dirección de la carga (en este caso, ejercicios verticales u horizontales).

10) Las condiciones de carga vertical y mixta son útiles para mejorar la fuerza en el ejercicio de sentadilla. Por lo tanto, se recomienda la inclusión de ejercicios dirigidos verticalmente cuando se busque optimizar los niveles de fuerza en sentadilla.

11) No hubo diferencias entre los ejercicios horizontales, verticales o una combinación de ejercicios horizontales y verticales con dispositivos isoinerciales para promover mejoras en el rendimiento de salto vertical y cambio de dirección.

12) Las mejoras en el salto vertical y el cambio de dirección fueron visibles después de una intervención de entrenamiento a corto plazo (cuatro semanas). Debido al congestionado calendario de la mayoría de los deportes de equipo, con periodos de pretemporada de aproximadamente cuatro semanas, este estudio destaca el entrenamiento con dispositivos isoinerciales como un estímulo efectivo para lograr adaptaciones de rendimiento en periodos de tiempo breves.

Estudio 4

13) La distribución variable o constante de la intensidad de los ejercicios con dispositivos isoinerciales son útiles para mejorar los niveles de fuerza. No obstante, la intensidad constante parece ser una mejor opción para mejorar el sprint de diez metros.

14) Otras tareas de rendimiento como el salto o el cambio de dirección, necesitan otro tipo de carga de entrenamiento, por ejemplo de menor intensidad y volumen o un entrenamiento complementario, para maximizar el rendimiento.

15) Los entrenadores de fuerza y acondicionamiento físico de jugadores de fútbol con una buena relación entre el nivel de fuerza y la masa corporal deberían individualizar la intensidad de los programas de entrenamiento con dispositivos isoinerciales y realizar entrenamiento complementario para promover mejoras específicas en el rendimiento específico.

Los hallazgos de esta tesis doctoral resaltan cómo diferentes variables mecánicas y antropométricas afectaron la producción de potencia y los valores de sobrecarga excéntrica en el entrenamiento con flywheel y su aplicación en los programas de entrenamiento. Los *estudios 1* y *2* incluidos en esta tesis muestran la importancia de la individualización del entrenamiento con estos dispositivos en función de la longitud de la cuerda, el nivel de altura de recogida, el tipo de ejercicio, las cargas inerciales, las características del deportista y el nivel de entrenamiento. En esta línea, los *estudios 3* y *4* recogidos en esta tesis muestran la importancia de programar el entrenamiento en función de las necesidades de rendimiento del deportista utilizando diferentes condiciones de carga e intensidad óptima. El entrenamiento con flywheel debe individualizarse no sólo en función del tipo de ejercicio y dispositivo a utilizar, sino también teniendo en cuenta el nivel de entrenamiento y las necesidades de rendimiento individuales de cada deportista.

6.3. Limitations and future directions

The studies included in this doctoral thesis are not free of limitations. At the same time, these limitations can be helpful to establish new research perspectives in the field of strength and conditioning. The limitations and future research objectives are outlined as follows:

1) No female subjects were included in studies *2*, *3* and *4*, so we cannot be sure whether these results could be extrapolated to the female population. Future research should be carried out to contrast the results of this thesis with those of other populations (elderly, young athletes, etc.).

2) Subjects in *study 3* had limited resistance training experience. This fact could favour the improvements independent of the loading conditions. Future studies are required to assess whether the influence of vertical, horizontal, or mixed exercise selection during flywheel training leads to distinct performance adaptations in athletes with higher resistance training experience.

3) Another factor that should be considered as a limitation in *study 3* is the slight difference in training volume (e.g., repetitions per session) and exercise type (bilateral versus unilateral), which may have affected the results of the present study.

4) At the same time, *study 3* attempted to replicate the pre-season context, the training intervention comprised only eight FRT sessions (i.e., 4 weeks – 2 sessions/week), which might be insufficient to find differences between the training groups. However, the present study design is in line with the real sports calendar and, therefore, represent a possible training scenario.

5) Anthropometrical measurements (i.e., changes in BM) were not performed in *studies 3* and *4*. As previous research demonstrated, the post-values could be conditioned by such changes. Future research should consider anthropometric changes to explain the outcomes in strength and conditioning programs.

6) Further, in *studies 3* and *4* the relatively small sample size and the lack of a control group limit the conclusions of the study. No control group was included because FRT was considered an important variable not only for optimizing strength in players but also for reducing the probability of injury. For this reason, and to have a greater number of players in each group, a control group was not included in these studies.

7) In *study 4*, the training volume and the incidence of friendly matches were very high, so it was not possible to minimize post-match fatigue levels.

8) In addition, although the training load was controlled and each player completed at least ninety percent of the sessions, the player´s position on the field and external training load may have influenced the results of *study 4*.

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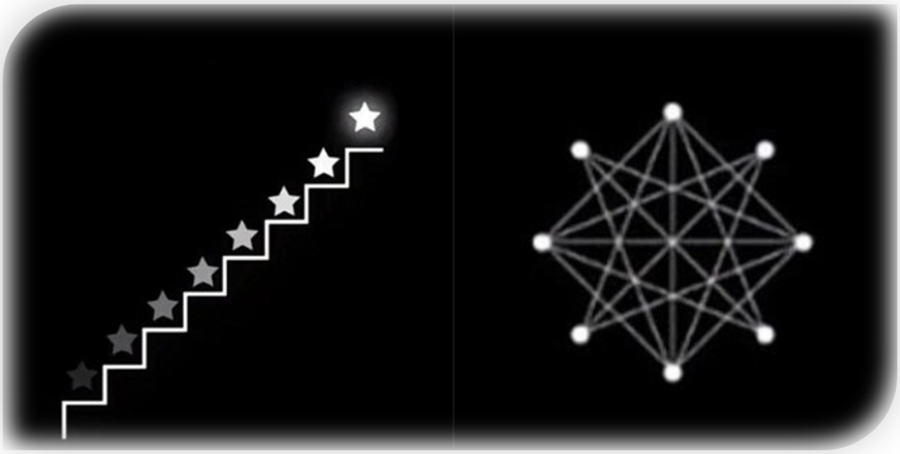
8. APPENDICES



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APPENDIX 1.

Note. This study was published.

8.1 STUDY 1: Sabido, R., Hernández-Davó, J. L., García-Valverde, A., Marco, P., & Asencio, P. (2020). Influence of the Strap Rewind Height during a Conical Pulley Exercise. *Journal of Human Kinetics*, *74*(1), 109–118. https://doi.org/10.2478/hukin-2020-0018

8. Chapter 8: Appendices. Appendix 1

Study 1: Influence of the strap rewind height during a conical pulley exercise

ABSTRACT

The use of flywheel devices has increased in popularity within resistance training programs. However, little is known about modifiable variables which may affect power output responses, as the rope length and the height level used in a conical pulley device. The aim of this study was to assess the influence of using three different rope lengths (1.5, 2.5 and 3.5 meters) and four different height levels (L1, L2, L3 and L4) on concentric peak power (PPconc), eccentric peak power (PPecc) and eccentric overload (eccentric/concentric PP ratio; EO) during conical pulley exercises (i.e. seated and stand-up row). A total of 29 recreationally trained subjects (25.3 ± 7.1 years; 1.74 ± 0.06 m; 72.5 ± 8.3 kg) took part in the study. Testing sessions consisted of 1 set of 10 repetitions under each condition; experiment 1: seated row exercise using the three different rope lengths; experiment 2: stand-up row exercise using four different height levels of the conical pulley. Results from experiment 1 did not show differences between rope lengths, although a trend for greater PPecc (ES=0.36-0.38) and EO (ES=0.40-0.41) was found when using longer rope lengths (2.5 and 3.5). Experiment 2 showed significant increases in both PPconc and PPecc as the height level used was closer to the cone base (L4). In contrast, EO values were significantly greater when using upper height levels (L1). These results suggest that the height level used during conical pulley exercises highly influences power output responses. Therefore, this variable should be carefully managed depending on the training goal (e.g. power vs hypertrophy).

Key words: *eccentric overload, strength, power output, flywheel.*

INTRODUCTION

Resistance training is probably the most common strategy aiming to optimize muscular force and power adaptations. It is broadly accepted that adaptations following resistance training programs are influenced by training intensity (Fry, 2004; Maszczyk et al., 2020). Traditional resistance exercises (e.g. free weight, weight stack machines), where the same absolute load is lifted and lowered, may not provide an optimal stimulus for eccentric (ECC) actions. Due to the greater force production capacity of ECC compared with concentric (CONC) actions, the use of the same absolute load lead to a lowered stimulus for ECC actions (Sogaard et al., 1996). This issue theoretically places traditional resistance exercises in disadvantage compared with other resistance training. Due to the benefits of ECC actions in neuromuscular adaptations, flywheel resistance training emerged as an effective way to enhance strength and power adaptations (Maroto-Izquierdo et al., 2017; Chen et al., 2018). When performed properly, flywheel exercises allow for higher ECC than CONC force values to be generated, leading to brief episodes of eccentric overload (EO) (Norrbrand et al., 2008).

The increased popularity of flywheel devices resides in their efficacy to increase muscular strength (Askling et al., 2003; Norrbrand et al., 2010) and power (Maroto-Izquierdo et al., 2016), as well as hypertrophy adaptations (Norrbrand et al., 2008) in healthy and well- trained populations. In addition, flywheel resistance training has also been proposed as a useful methodology to improve dynamic athletic performance (Maroto-Izquierdo et al., 2017; Blazek et al., 2019). Sports movements demand the production of maximal power in unpredictable and variable contexts, with an emphasis on eccentric and multidirectional components (Gonzalo-Skok et al., 2017). Thus, considering the principle of specificity, exercises that accentuates force and power production during the ECC phase should be more present in resistance training workouts (Gonzalo-Skok et al., 2017).

Among flywheel devices, the conical pulley is commonly used both in practice and science (Beato et al., 2019; Fernández-Gonzalo et al., 2014; Gonzalo-Skok et al., 2017; Gonzalo-Skok et al., 2019; Timon et al., 2019). This device operates from the energy created by winding and unwinding a rope wrapped around a vertical cone-shaped shaft (Nuñez et al., 2017). In contrast to other flywheel devices, conical pulleys allow for coupled CONC and accentuated EO muscular actions at high velocities while conducting specific and multidirectional movements (Gonzalo-Skok et al., 2017; Nuñez et al., 2017). The importance of reaching EO values should be highlighted , as force increases after a flywheel training program are higher with the existence of EO during training (Nuñez and Saez de Villarreal, 2017). In conical pulley devices, the exercise intensity can be adjusted through two different modes: (a) by adding or removing any number of the 16 weights located on the edge of the flywheel; and (b) by selecting one of the four height levels that will change the location of the pulley, height level 1 being the upper position (where the rope winds around the narrowest diameter of the cone) and level 4 being the lowest position (wider part of the cone) (Moras et al., 2018; Moras et al., 2019). Although not reported in most studies, the selection of the height level influences the geometrical factor (i.e. radius) of the conical pulley, which consequently affects force production (Norrbrand et al., 2008).

The inertial load used during flywheel exercises is usually reported in the articles, and several researches have shown the influence of using different inertial loads on force and power output performance during flywheel resistance exercises (Martínez-Aranda et al., 2017; Piqueras-Sanchiz et al., 2019; Sabido et al., 2018; Vazquez- Guerrero et al., 2016). Specifically, light inertial loads allow for greater CONC and ECC power output to be produced, whereas EO (eccentric/concentric ratio) is maximized when using high loads. Further, Sabido et al. (2019) showed beneficial performance adaptations (e.g. linear sprint and change of direction ability) following a flywheel training intervention based on light (0.025 kg·m^2) vs high (0.075 kg·m^2) inertial loads. However, due to the novelty in the use of conical pulleys in research, little is known about how strength and conditioning coaches can manage changes in flywheel resistance exercises through modifications of further variables. To the best of authors' knowledge, only Vazquez- Guerrero et al. (2016) studied the influence of the height level used in the conical pulley. In that study, greater velocities but lower force values were found when using a greater radius of the cone. However, power output responses to different height levels have not been analyzed in previous studies. In addition, by modifying the rope length, conical pulley exercises can be performed close or far to the device. Whether this variable may affect power output has not previously been analyzed. Therefore, based on the scarcity of research regarding alternative variables (i.e. rope length and height level), and the potential influence of these variables on power output responses, the aim of this study was to analyze the influence of using three different rope lengths and four different height levels during conical pulley resistance exercises on concentric peak power, eccentric peak power and EO. We hypothesized that using lower positions of the conical pulley, greater concentric and eccentric power output can be achieved. In addition, the authors hypothesized that power output will increase when using longer rope lengths.

METHODS

Experiment 1: Rope length

Participants

Fourteen recreationally trained participants took part in this experiment: nine men (age: 29.4 ± 7.2 years; weight: 75.8 ± 6.8 kg; height: 1.75 ± 0.02 m) and five women (age: 27.8 ± 5.7 years; weight: 63.6 ± 3.2 kg; height: 1.68 ± 0.03m). All participants were recreational athletes from different sports (e.g. soccer, handball, tennis), and reported at least two years' experience in resistance training, including the row exercise. None of them reported previous experience with flywheel exercises. All participants were carefully informed about the potential risk of the testing sessions and signed a written informed consent approved by the Ethics Committee of the University in accordance with the Declaration of Helsinki (2013) before participation. Participants were informed that they were able to voluntarily withdraw from the study at any moment. To avoid experimental variability, the same researcher conducted all testing sessions, and subjects were scheduled at the same time for each session. Throughout the investigation, participants were requested to maintain their regular diets and normal hydration state, not to take any nutritional supplementation or anti-inflammatory medications, and to refrain from caffeine intake in the 3 hours before each testing session. Strength training sessions were not allowed at least 72 hours before the experimental sessions.

Procedures

Two weeks prior to the test, the participants conducted two familiarization sessions (one per week) aiming to learn the protocol and the correct technique to perform the exercise in the conical pulley device. A previous study with flywheel devices reported that two familiarization sessions are required before finding reliable and stable power output values during flywheel exercises (Sabido et al., 2017). Both familiarization and testing sessions consisted of three sets of ten repetitions of the seated row exercise using a conical pulley device. Before testing, all participants completed a general warm-up, including 5 minutes of jogging and dynamic stretching. Afterwards, a more specific warm-up consisting of a barbell row set of 10 submaximal repetitions, and one set of the seated row exercise with the conical pulley was performed. Participants were seated in an adjustable fitness chair leaning the chest on the backrest to facilitate stabilization of the body, with the knee joint bent at a 90-degree angle, the back flat in a neutral vertical position and a pronated grip for the handle. Execution of the exercise proceeded by the subject making a full elbow flexion in the CONC phase and a full extension in the ECC one. During the whole movement, participants were required to keep the chest in contact with the chair. Within each session, all participants performed one set of 10 repetitions with each of the different rope lengths (1.5, 2.5 and 3.5 m) in a random order. During this protocol, the height level employed in the conical pulley remained fixed (at level 1), and the mass consisted of 6 loads of 900 grams each, resulting in an inertial load of 0.15 $kg \cdot m^2$. Subjects were fully encouraged to perform the CONC phase at a maximal velocity, and to try to perform a sudden braking action at the end of the ECC phase. Three minutes of recovery time was established between sets.

The conical pulley included an optical receiver (SmartCoach, Europe AB, Stockholm, Sweden) coupled to the device, recording data of each repetition in both the CONC and ECC phase of the movement. Then, a specialized software (SmartCoach Power Encoder, Europe AB, Stockholm, Sweden) was used to process all data, using the variables concentric peak power (PPconc), eccentric peak power (PPecc) and eccentric overload (EO; eccentric/concentric ratio) for analysis. A high reliability of this encoder has been previously reported (Sabido et al., 2017). Data included for analysis were the mean of all the repetitions of the set (Sabido et al., 2017).

Experiment 2: Height level

Participants

Fifteen recreationally trained males (age: 22.0 ± 1.3 years; weight: 73.5 ± 7.6 kg; height: 1.77 ± 0.04 m) were involved in the second experiment. All participants were recreational soccer players from the University team. Participants reported at least 2 years' experience in resistance training, although none of them had experience in flywheel training. All methodological issues were the same as reported in the 'Participants' section of Experiment 1.

Procedures

Participants were required to attend a total of four testing sessions (one per week), consisting of four sets of ten repetitions (one set per each height level) of the stand-up row exercise (pronated grip) using the conical pulley device. Due to the previously published necessity of a familiarization process with flywheel devices (Sabido et al., 2017; Tous-Fajardo et al., 2006), data used for analysis were from the fourth testing session. During this experiment, both inertial load (6 loads) and rope length were unmodified. Nevertheless, each set was performed using a different height level (1, 2, 3 and 4) in the conical pulley (Figure 1). There were 5 cm distances between each height level. To avoid potential cumulative fatigue effects, subjects were divided into an 'ascending order' (starting from the bottom of the cone: height level 4) and a 'descending order' (starting from the top of the cone: height level 1) group (Sabido et al., 2017). In addition, 3 minutes rest intervals were allowed between sets.

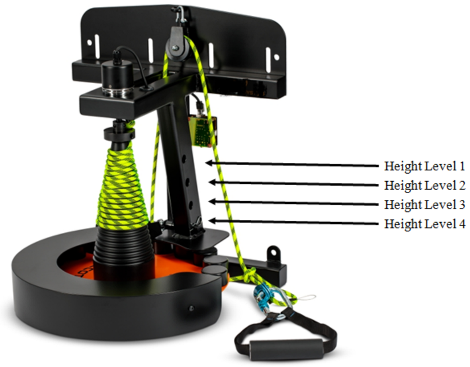

Figure 1. Picture of the conical pulley and the position of the four different height levels.

The stand-up row exercise was performed starting with a full elbow extension position. Then, participants were required to pull the handle until the bar touched the chest at a height below the nipples. Additionally, to prevent imbalance during the movement execution, a stable rigid support was placed in front of the subjects, allowing them to firmly place their feet. As in Experiment 1, participants were instructed to perform the CONC phase as fast as possible and to delay the braking action to the last part of the ECC phase. Likewise, mechanical data were recorded and analyzed by the specialized software (SmartCoach), using PPconc, PPecc and EO for analysis.

Statistical analysis

All data were analyzed using the statistical package SPSS 22.0 (SPSS Inc, Chicago, IL, USA). After testing the normality of the data using a Kolmogorov−Smirnov test, a one-way ANOVA was used to analyze differences in the different variables (PPconc, PPecc, and EO) when using the four different height levels. The same procedure was used for analyzing data regarding rope length. Statistical significance was set at $p < .05$. In addition, the magnitude of the differences was calculated using Cohen's d and interpreted for a recreationally trained sample (1−5 years' experience in resistance training) following Rhea (2004), as $d < 0.35$ (trivial); $d = 0.35−0.8$ (small); $d = 0.8−1.50$ (moderate); $d > 1.5$ (large).

RESULTS

Experiment 1: Rope length

Data of PPconc, PPecc and EO with the different rope lengths are shown in Table 1. Non- significant differences were found for any variable. Nevertheless, there was a trend for significantly higher PPecc values as the rope length increases (small ES). Similarly, EO was close to significance when comparing length 1 (1.5 m) with length 3 (3.5 m) ($p = .056$; ES = 0.41; small).

Table 1. Data of PPconc, PPecc and EO by rope length.

Variable	Length 1	Length 2	Length 3
PPconc (W)	360 ± 120	378 ± 107	373 ± 92
PPecc (W)	423 ± 143	479 ± 153	472 ± 127
EO	1.18 ± 0.20	1.27 ± 0.25	1.26 ± 0.19

Experiment 2: Height level

Data of PPconc when using each of the four height levels in the pulley are shown in Figure 2. The highest position of the pulley (level 1) caused significantly lower values than level 2 (480 ± 155 vs 576 ± 172 W; ES = 0.59; small), level 3 (480 ± 155 vs 678 ± 246 W; $p < .001$; ES = 0.96; moderate) and level 4 (480 ± 155 vs 760 ± 245W; $p < .001$; ES = 1.37; moderate). In addition, PPconc in level 4 was significantly higher than in level 3 ($p = .037$;

ES = 0.33; trivial) and level 2 (p < .001; ES = 0.87; moderate). The difference in PPconc between levels 2 and 3 was close to significance (p = .055; ES = 0.48; small).

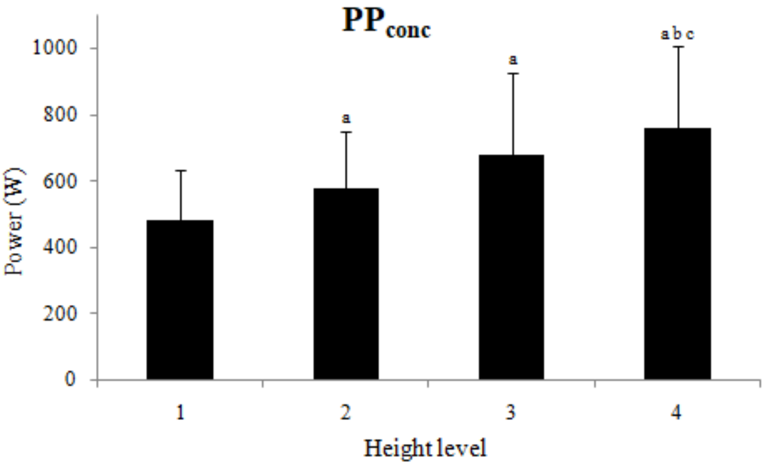

Figure 2. Data of PPconc by height level. a = significantly higher than level 1; b = significantly higher than level 2; c = significantly higher than level 3.

The values of PPecc with each height level are shown in Figure 3. When using level 1, significantly lower PPecc values were found compared with level 3 (602 ± 341 vs 717 ± 293 W; p = .014; ES = 0.36; small) and level 4 (602 ± 341 vs 766 ± 258 W; p = .012; ES = 0.54; small). In addition, significantly higher values were found when using the level 4 compared with the level 2 (766 ± 258 vs 649 ± 256W; p = .015; ES = 0.46; small).

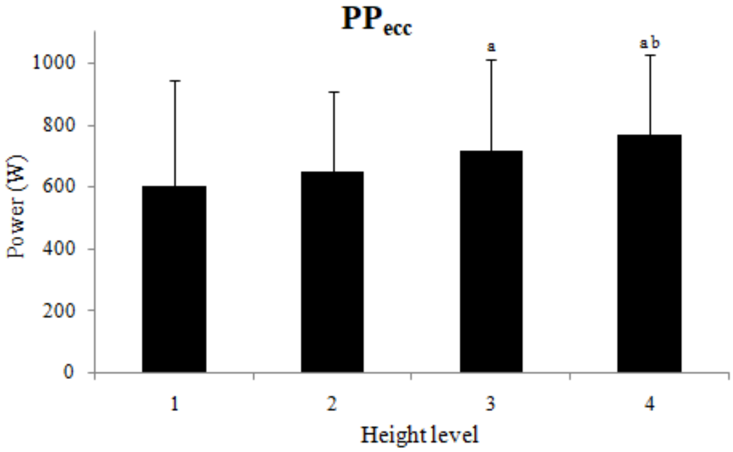

Figure 3. Data of PPecc by height level. a = significantly higher than level 1; b = significantly higher than level 2.

Conversely, for EO (eccentric/concentric ratio), the higher values were found in level 1, being significantly greater than those in levels 2 (1.22 ± 0.27 vs 1.11 ± 0.16; p = .046; ES

= 0.50; small), 3 (1.22 ± 0.27 vs 1.06 ± 0.18; p = .002; ES = 0.70; small) and 4 (1.22 ± 0.27 vs 1.01 ± 0.13; p = .002; ES = 0.99; moderate). In addition, EO values in level 2 were significantly higher than in level 4 (1.11 ± 0.16 vs 1.01 ± 0.13; p = .009; ES = 0.69; small), and close to significance compared with level 3 (1.11 ± 0.16 vs 1.06 ± 0.18; p = .053; ES = 0.29; trivial).

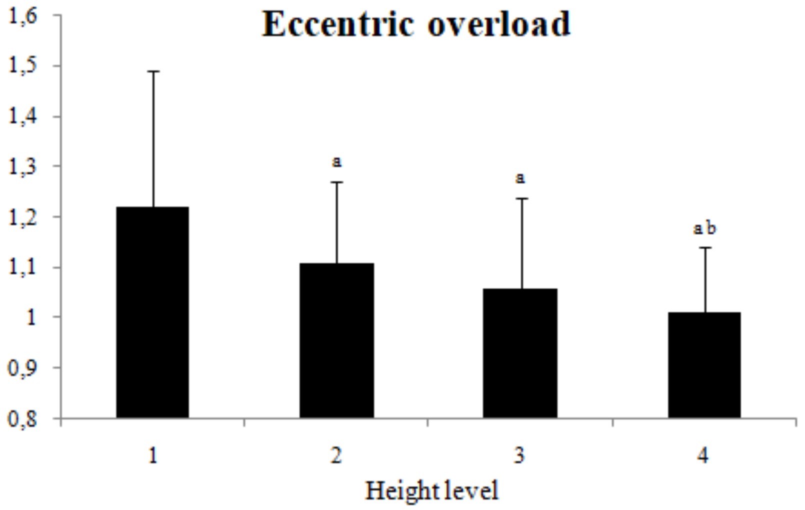

Figure 4. Data of EO (eccentric/concentric ratio) by height level. a = significantly lower than level 1; b = significantly lower than level 2.

DISCUSSION

The present study aimed to assess the influence of two different modifiable variables (rope length and height level) on power output during two flywheel resistance exercises using a conic pulley device. The main finding of the first experiment was the lack of significant differences in PPconc, PPecc and EO when using rope lengths of either 1.5, 2.5 or 3.5 m. Nevertheless, a trend for increases in PPecc and EO (small ES) was found with greater rope lengths. The second experiment provided important information about the meaningful influence of the height level used in the conic pulley. Thus, significantly higher values of PPconc (760 vs 460 W) and PPecc (766 vs 602 W) were found when comparing the lowest with the highest position of the cone. In contrast, the greater EO values were found when using the highest position of the cone (1.22 vs 1.01).

Among the different variables that may affect power output when using these devices, including the inertial load used and the geometric (diameter and thickness) properties of the flywheel (De Hoyo et al., 2015), variables such as rope length and the height level in the conic pulley have received little attention. To the best of our knowledge this is the first study evaluating the influence of using different rope lengths during a flywheel resistance exercise on power output. The results showed a trend for greater PPecc and EO values as the rope length increased from 1.5 to 3.5 m, with small effect sizes ranging from 0.36 to 0.45. Even when using the same height level in the conical pulley, the rope length slightly influenced the position of where the rope winds and unwinds. Specifically, a greater length would lead the rope to be wound in a lower position of the cone, which presents a greater diameter. It could be hypothesized that this greater diameter allows for a greater linear movement velocity (Vázquez-Guerrero et al., 2016), favoring to some extent the higher values of PPecc and, as a consequence, the increases in EO values. However, in spite of the great difference in the rope length used (1.5 vs 3.5 m) differences in power output and EO values did not reach statistical significance. Therefore, it seems that variations in rope length are not a key factor when using flywheel exercises.

The use of flywheel exercises allows for different ways to change the resistance to the movement offered by the device. Previous researches have already shown how both force and power output are affected by the inertial load used (Martínez-Aranda et al., 2017; Sabido et al., 2018). Nevertheless, only one previous study (Vázquez-Guerrero et al., 2016) has investigated the effect of the position (height) of where the rope winds/unwinds in the conical pulley on force production. This previous study showed that higher mean and peak forces were produced when using higher positions of the cone. The authors highlighted that, without modifying the height level, a change in the moment of inertia higher than a 55% is needed to significantly modify power output, whereas changing only one height level led to significant power output changes. These results emphasized the importance of height level management to obtain different power output responses. Similarly, the results of the present study showed a significant influence of the height used in all the variables measured (PPconc, PPecc and EO). In particular, PPconc is the variable most affected by the height used, the lowest position (corresponding with the greater cone diameter) being where greater PPconc values were obtained. Further, it seems that a quite linear relationship exists between the change in the pulley height and changes in PPconc, increasing this PPconc by approximately 15% as the pulley is placed in the next (wider) position. Similarly, PPecc also increased when lower heights of the pulley were used (Figure 3). Nevertheless, the slope of the changes when modifying the height levels seems to be less pronounced. Specifically, in the present study, PPecc increased by approximately 8% as the pulley was placed in the next (wider) position. This almost linear relationship between changes in the height level and modifications in power output may be used by coaches to accurately prescribe flywheel training. Thus, by modifying the height position of the pulley and using wider cone diameters, athletes can perform not only faster movements, but also actions producing higher power outputs. This last fact may have consequences for dynamic athletic performance, as a previous research (Sabido et al., 2019) has shown favorable results in linear sprint and change of direction performance when using flywheel devices configured to allow higher velocities and PP values (i.e. low inertial loads) compared with lower velocities (i.e. high inertial loads). A potential explanation of the superior usefulness of flywheel devices configured to allow for greater velocities may be linked to velocity specificity of resistance exercise (Behm and Sale, 1993). Thus, the faster the movement performed in the flywheel exercise is, the greater the transference to explosive actions.

Contrarily to peak power values, EO was significantly greater when using higher positions of the conical pulley. Thus, when the rope is wound/unwound in the narrowest (smaller diameter) part of the cone, greater EO values can be achieved. A potential explanation for the greater EO values when using small diameters may be the lower movement velocities reached.

These lower velocities allowed the subjects to perform a longer muscle action, allowing to greater force values to be achieved. Using greater height levels in the pulley entail similar responses as increasing the inertial load, causing lower PP values, but increasing EO (Sabido et al., 2018). Although greater PP output could be useful for more functional-oriented exercises, greater EO values may be a key factor for muscular adaptations. The ability to produce great eccentric forces at long muscle lengths (as when using flywheel devices) has been linked to greater hypertrophy effects (Noorkoiv et al., 2014). Consequently, it can be hypothesized that the use of higher positions in the conical pulley may be a more effective option when looking for muscular hypertrophy. In this line, increases in electromyographic activity as well as in muscle cross section area has been previously reported following flywheel training (Norrbrand et al., 2008; Tous-Fajardo et al., 2006). Further, a review of flywheel training has shown that increases in force are higher with the existence of greater EO values (Nuñez-Sanchez and Saez de Villarreal, 2017). Thus, when aiming to develop muscular strength, the use of higher positions of the conical pulley would be a better choice.

CONCLUSIONS

The results of the present study provide important information to optimize the use of flywheel resistance devices. By increasing the rope length during an exercise, slightly greater PPecc and EO values can be achieved, although not significant differences were found. Nevertheless, the factor influencing greater PPconc, PPecc and EO is the height level used in the conic pulley. Specifically, bottom positions of the cone (great diameters) allow for greater PPconc and PPecc to be produced, while top positions (small diameters) caused greater EO values. Strength and conditioning coaches can use data provided in the present study for prescribing flywheel resistance exercises according to the aim of the training session. Thus, within a resistance training periodization, conical pulley exercises should be performed using a higher position, when aiming to greater force and hypertrophy adaptations. However, in training periods close to competitions, the use of lower positions of the cone is recommended, as they allow for greater peak power output.

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APPENDIX 2.

Note. This study was published.

8.2 STUDY 2: Asencio, P., García-Valverde, A., Albaladejo-García, C., Beato, M., Moreno, F. J., & Sabido, R. (2024). Analysis of Concentric and Eccentric Power in Flywheel Exercises Depending on the Subjects' Strength Level and Body Mass. *Journal of strength and conditioning research.* 10.1519/JSC.0000000000004818. Advance online publication. https://doi.org/10.1519/JSC.0000000000004818

Appendix 2

Study 2: Analysis of Concentric and Eccentric Power in Flywheel Exercises Depending on the Subjects' Strength Level and Body Mass.

ABSTRACT

The objective of this study is to describe how flywheel exercise mechanical outputs are affected by the athletes' body mass and strength level and by the exercise type. Forty-six recreational athletes came to a laboratory three times. On the first day, descriptive data, squat (one-repetiton maximum: 1RM) and flywheel familiarization were performed. After a second day of familiarization, subjects performed a randomized flywheel exercise-testing protocol of squat and split squat exercises. The ariables used for data analysis were peak concentric and eccentric power (PP_{conc}, PP_{ecc}), eccentric/concentric ratio and their relationship with 1RM/body mass. Subjects were assigned to a stronger or weaker group according to their 1RM/body mass ratio. Group differences were found in absolute values of eccentric overload ($p < 0.01$; effect size = 0.51) and eccentric overload/body mass ($p < 0.01$; effect size = 0.46) only in the split squat. Absolute power values in the concentric phase showed differences between inertial load ($p < 0.01$; effect size = 0.41). The stronger group did not present significant differences between inertial loads during squat ($p < 0.01$; effect size = 0.46) but they showed different ratios with light inertias in comparison with the weaker group ($p < 0.01$; effect size = 0.46). There were significant differences between groups with light inertias in split squat (non-dominant) and squat exercises ($p < 0.05$; effect size = 0.29) in the eccentric and concentric phases ($p < 0.116$; effect size = 0.20). Squat and split squat exercises present different profiles depending on the training level. In conclusion, it is recommended that practitioners perform a test to understand the inertial load–power profile (concentric, eccentric and their ratio) for each exercise and also consider the user's strength level for selection of the inertial load as well as for the exercise to use in training.

Key words: *flywheel squat; flywheel split squat; power; eccentric overload; inertial loads.*

INTRODUCTION

Strength and power play a crucial role in athletic preparation for success in many sports (15). As power is the product of velocity and force (7) athletes' strength level is a determinant variable for increasing power outputs (1, 6). In this way, several studies found an improvement in performance with power training in sports such as soccer (13) or basketball (37). Therefore, it seems a relationship exists between high–lower limb power output and sport-specific ability (1, 4, 27). From a training perspective, one criterion to identify the right training intensity is to evaluate the load that allows subjects to achieve peak power in a specific exercise (7, 15, 19). It is important to remember that peak power can vary depending on some variables such as the athlete's strength level (38), training experience (7, 18) or type of exercise (9).

Flywheel resistance training uses a rotating mass that stores and releases kinetic energy during exercise. This training has been shown to improve strength (28), power (23), change of direction (11), countermovement jump (11) and sprinting ability (11) in different populations as well as to generate morphological adaptations (e.g., hypertrophy) (28). To maximize the training effect of flywheel resistance technology, practitioners use an inertial load that allows them to reach the desired mechanical outputs (e.g., power) (23). Training intensity with flywheels is usually monitored based on the power output, which is the product of inertial load (i.e., the combination of discs used) and rotational velocity. Flywheel resistance exercise can be divided into concentric and eccentric phases . It is common to report mechanical output data for both phases, as well as their ratio (eccentric/concentric ratio), which assesses the presence of an eccentric overload (EOL) (11). Flywheel resistance training produce an EOL when a specific mechanical output (e.g., mechanical power) is greater during the eccentric phase than during the concentric phase (20, 25). Previous research showed an inverse relationship between load and power outputs and a positive relationship between load and EOL (24, 31, 35). Therefore, practitioners can modify the intensity by changing the flywheel inertial load to provide changes in the mechanical outputs of interest (e.g., concentric power and eccentric power) (2).

Because of the importance of concentric and eccentric mechanical output maximization during training, previous authors (2, 23) suggested practitioners should determine inertia–power and inertial velocity profiles of their athletes to select the most suitable inertial load for each user (42); however, the inertia–power profile is the most commonly used approach because of the difficulty of assessing velocity in the applied scenarios (e.g., lack of time or technology) (23). Use of a inertia–power profile to individualize peak power output is supported by previous authors (10), who used this approach to maximize the benefits of squat exercises. However, even with the latest research around flywheel resistance training monitoring (23), we do not have exhaustive evidence for optimization of mechanical outputs during training when the athlete's characteristics and exercises are manipulated. Practitioners need to know more regarding the impact that athletes' characteristics such as body mass (BM) and strength level have on power outputs (e.g., the importance of familiarization) (2, 3).

An important variable to determine the inertia–power profile is the type of movement used during the test. Unilateral movements such as the split squat, are a way to improve sport performance (45) and provide training variations (39). In certain contexts, their use has shown greater benefits versus bilateral movements (45). In the field of flywheel resistance training, three studies on the effects of unilateral and bilateral training (15, 17, 29), show similar improvements in jump or change of direction with both types of training but with slightly greater benefits for unilateral versus bilateral training. Although program duration and total volume were similar in the three studies (6–8 weeks; two sessions per week with four or six sets), training intensities were different. Two of the studies chose low inertial loads to obtain greater power peaks during the movements (15, 17), while the third used higher inertial loads to maximize EOL (29).

Due to the limited evidence currently available around the influence of BM, strength level and different exercises on power, EOL and velocity, this research is warranted. The objective of this study is to describe how mechanical outputs are affected by the athletes' BM, strength level and the exercise performed. We hypothesized the athletes' BM and strength level will allow greater absolute mechanical outputs to be achieved, and these outputs will be exercise dependent.

METHODS

Experimental approach to the problem

Differences in flywheel resistance exercise variables between stronger and weaker athletes in squat and split squat exercises were investigated. After a familiarization procedure and testing, the subjects enrolled were classified according to their strength level. After a standardized warm-up protocol, they performed a randomized and counterbalanced exercise protocol (experimental conditions) where flywheel resistance exercises were performed with different inertial loads and exercises (see Figure 1).

Participants

Forty-six recreational athletes took part in this study. Participants had at least one year of experience in resistance training but no experience with flywheel resistance devices. Subjects were assessed for their one-repetition maximum (1RM) and BM, both expressed in kilograms, and were subsequently assigned to one of two groups according on the training level based on their 1RM/BM ratio (14). The cutoff level for each group was performed following James et al.'s (18) criteria to classify the subjects according to their strength level in the back squat exercise: <1.5RM/BM for the weaker group; >1.5RM/BM for the stronger group.

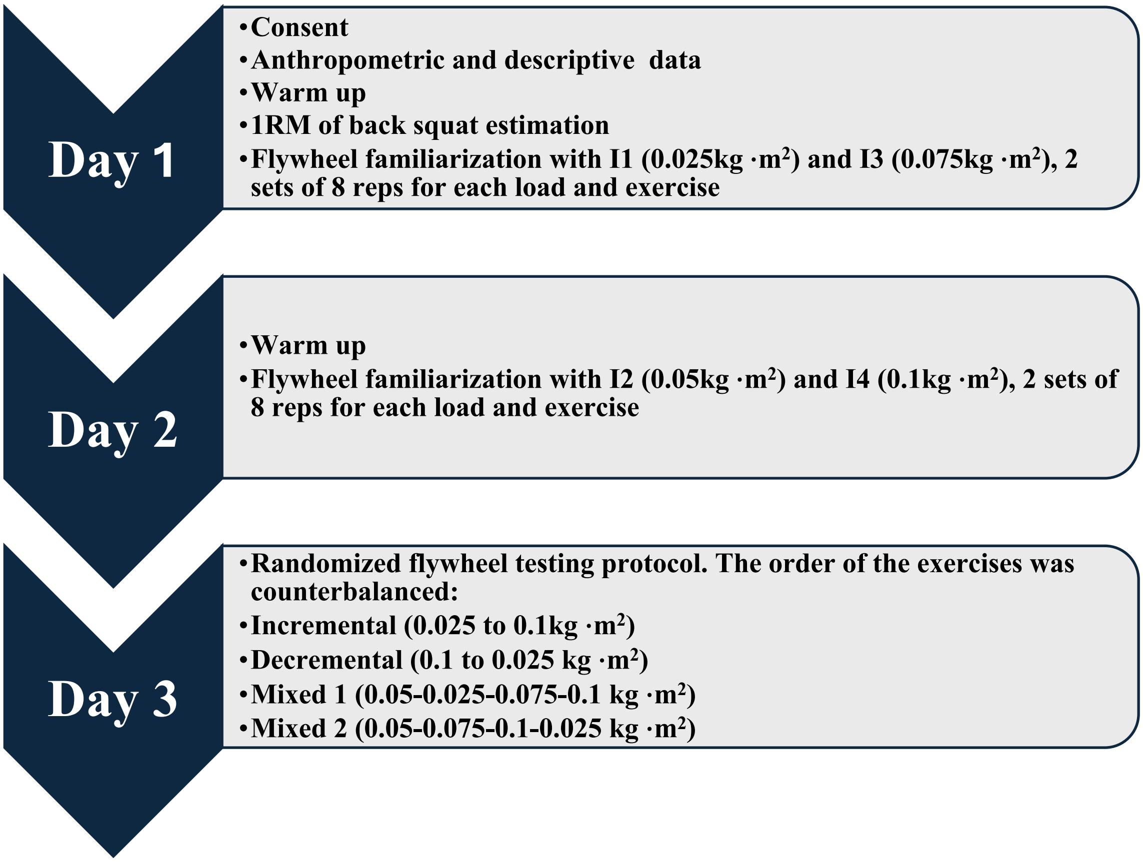

Figure 1. Scheme of the procedure.

A stronger group (*n* = 28; 27.42 ± 5 years; 1.74 ± 0.06 m; 72.53 ± 7.96 kg; 1RM = 129.5 ± 16.94; 1RM/BM = 1.79 ± 0.15) and a weaker group (*n* = 18; 26.1 ± 5.23 years; 1.77 ± 0.08 m; 78.22 ± 15.34 kg; 1RM = 115.16 ± 28.46 kg; 1RM/BM = 1.24 ± 0.13) were identified. Participants provided written informed consent in accordance with the Declaration of Helsinki and the experimental protocols were approved by the ethics committee of the university (Code: ADH.DES.RSS.PAV.23).

Procedures

Participants came to the laboratory on three separate occasions (72 h of recovery between sessions). On the first day, descriptive (e.g., age, training level) and anthropometric data were recorded for each participant. After that, the 1RM back squat and flywheel familiarization protocols were completed (36). On the second day, another flywheel familiarization protocol took place. On the last day, randomized flywheel exercise protocol was performed. The variables used for data analysis were peak concentric power (PP_{conc}), peak eccentric power (PP_{ecc}) and the eccentric/concentric ratio. Their relationship with the

1RM/ BM ratio was calculated for squat and split squat exercises. Test reliability for these tasks was published in previous studies (35). The values for ICC ranging from 0.79 to 0.93, and from 7.5% to 13.2 for CV.

Testing

On the first day, subjects completed a 1RM back squat exercise recorded using a linear encoder (T-Force System, Ergotech, Murcia, Spain) with a software application to calculate the relevant kinetic and kinematic parameters. For the 1RM estimation, participants performed a protocol previously described by Loturco et al. (21). Briefly, this consisted of squatting with a shoulder-width stance and the barbell rested on the upper back, approximately at the level of the scapular acromion, with the knees and hips fully extended. Each participant descended until their thighs were parallel to the ground and then ascended to the upright position. Participants started with a load representing 50% of their BM and thereafter the load was gradually increased until the mean propulsive velocity was < 0.5 m · s^{-1}. Using this submaximal load, participants performed three repetitions whereby concentric phases were performed as fast as possible, with an attached linear position transducer, it was possible to automatically estimate the 1RM of the athletes. The rest interval between sets was 4 minutes. The 1RM was estimated through movement velocity, as previously described (21). The coefficient of variation of the test was 9.7% and the intraclass correlation coefficient was 0.82.

Flywheel resistance exercise protocol

During the last testing day, subjects completed trial with a randomized load protocol (Incremental, Decremental, Mixed 1, Mixed 2), doing one maximum set of 10 repetitions with the addition of two initial repetitions needed to initiate the flywheel movement (35). The inertial loads used during the squat and split squat exercises were 0.025 (I1), 0.05 (I2), 0.075 (I3) and 0.1 kg·m^2 (I4). After each set, according to Sabido et al. (36), the participants resting for two (for I1 and I2) or three (for I3 and I4) minutes. During each repetition, both the concentric and eccentric power were recorded using an encoder and subsequently analyzed (SmartCoach Power Encoder, Europe AB, Stockholm, Sweden).

Statistical analysis

Statistical analyses were performed using the R-Studio program (4.0.2 version). By using the bootstrapping technique with 1000 randomly bootstrapped samples, a reliable estimate of 95% was determined for the confidence interval. The data were shown as the average of the mean of eight repetitions for each set (36). Values were compared between the different inertial loads and exercises through a two-factor ANOVA test (different inertias and training levels based on the 1RM/BM ratio). If necessary, the Bonferroni post hoc test was carried out for pairwise comparisons. The level of statistical significance was set at $p <$

0.05. To assess the magnitude of the changes, a Cohen effect size (ES) calculation was performed, interpreted as trivial (< 0.2), small (0.2–0.5), moderate (0.5–0.8) and large (> 0.8) (33).

RESULTS

Our results show there were differences between inertial loads for absolute EOL inertial loads [see Figure 2; *F*(3, 468) = 9.76; $p < 0.01$; ES = 0.51; 95% CI(18.9, 24.5)]. Similar results were found for EOL/BM between inertial loads during the split squat exercise [see Figure 3; *F*(3, 468) = 8.68; $p < 0.01$; ES = 0.46; 95% CI(0.28, 0.32)] but this pattern is not repeated exactly the same in the squat exercise [see Figure 3; *F*(2, 468) = 1.28; $p = 0.280$; ES = 0.20; 95% CI(0.27, 0.33)]. In addition, for the absolute power values in the concentric phase there were differences between inertias [see Figure 4; *F*(3, 468) = 6.62; $p < 0.01$; ES = 0.41; 95% CI(806, 852)] but no differences were found in the eccentric phase [see Figure 5; *F*(3, 468) = 1.68; $p < 0.171$; ES = 0.20; 95% CI(962, 1001)].

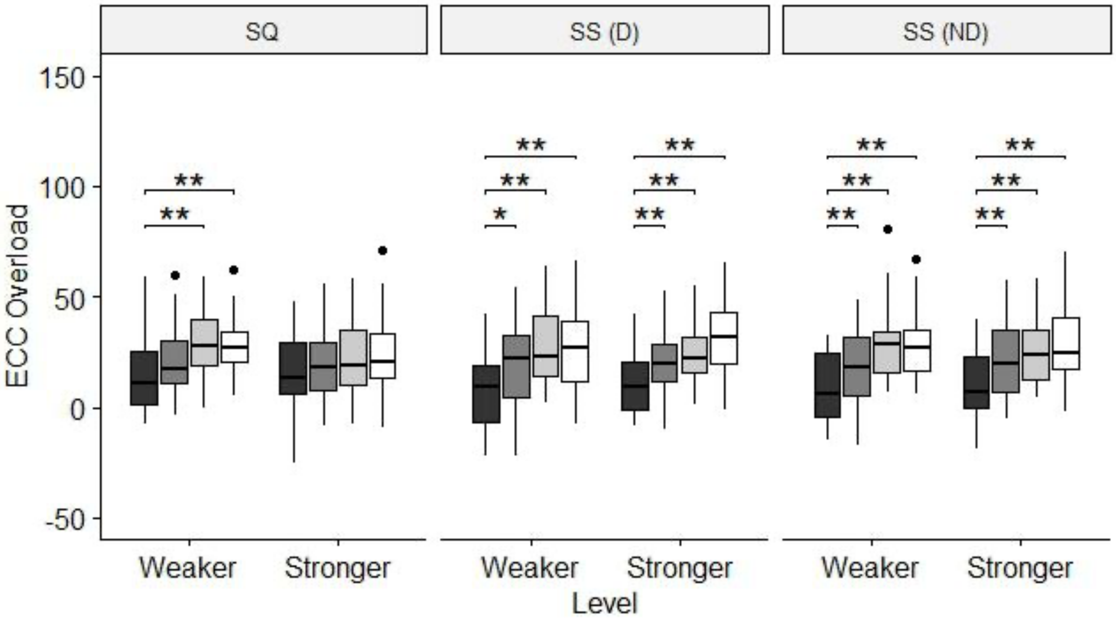

Figure 2. Inter-group comparison of inertias and eccentric overload values for squat (SQ) and split squat (SS) dominant (D) and non-dominant (ND) exercises (*$p < 0.05$; **$p < 0.01$). The different inertia values (1–4) are reported in different colors (black, dark grey, light grey and white), respectively.

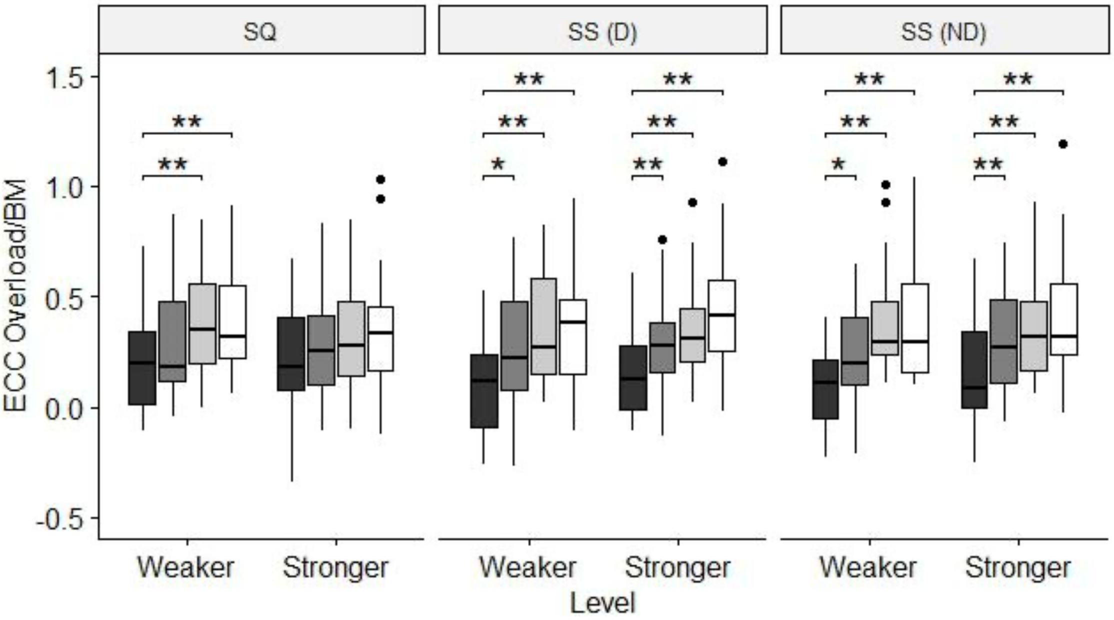

Figure 3. Inter-group comparison of inertias and eccentric overload/body mass (EOL/BM) ratio for squat (SQ) and split squat (SS) dominant (D) and non-dominant (ND) exercises (*$p < 0.05$; **$p < 0.01$). The different inertia values (1–4) are reported in different colors (black, dark grey, light grey and white), respectively.

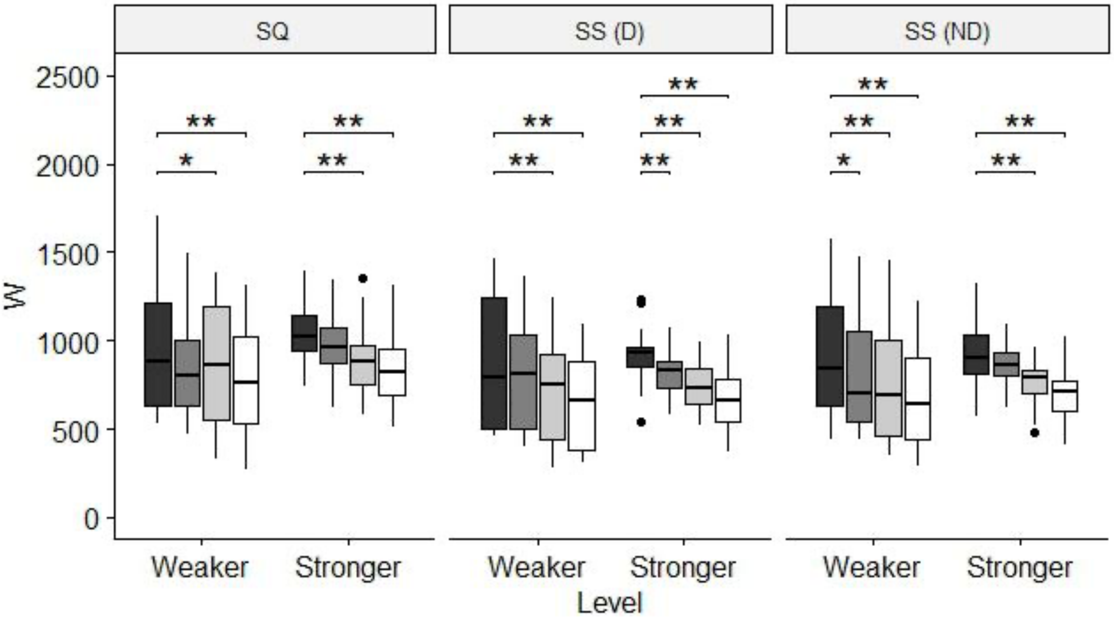

Figure 4. Inter-group comparison of inertias and concentric power values for squat (SQ) and split squat (SS) dominant (D) and non-dominant (ND) exercises (*$p < 0.05$; **$p < 0.01$). The different inertia values (1–4) are reported in different colors (black, dark grey, light grey and white), respectively.

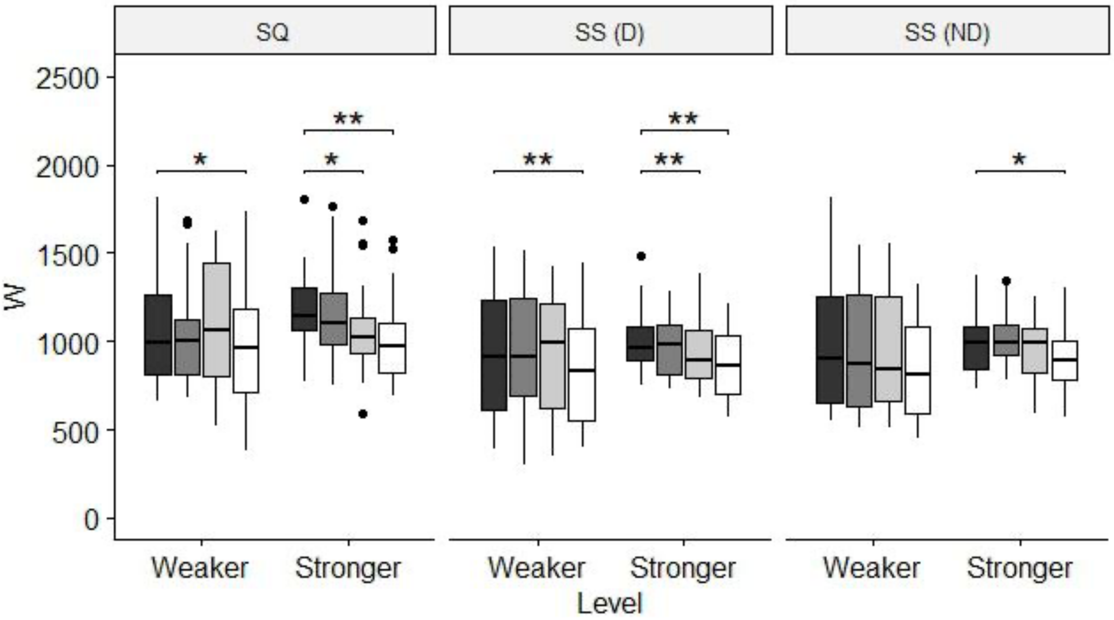

Figure 5. Inter-group comparison of inertias and eccentric power values for squat (SQ) and split squat (SS) dominant (D) and non-dominant (ND) exercises (*$p < 0.05$; **$p < 0.01$). The different inertia values (1–4) are reported in different colors (black, dark grey, light grey and white), respectively.

Stronger group did not present significant differences between inertial loads during the squat exercise [see Figure 2; $F(3, 468) = 8.68$; $p < 0.01$; ES = 0.46; 95% CI (16.44, 23.74)]. We found both the stronger and the weaker group were influenced by inertial loads in both exercises for the concentric phase related to BM. However, stronger participants showed higher concentric ratios in I1 and I2 in comparison with the weaker group [see Figure 6; $F(3, 468) = 7.50$; $p < 0.01$; ES = 0.46; 95% CI(11.63, 12.44)]. In the eccentric phase, moreover, there were significative differences between the stronger and weaker groups in I2 in the split squat (non-dominant) and in I1 and I2 in the squat exercises [see Figure 7; $F(3, 468) = 4.58$; $p < 0.05$; ES = 0.29; 95% CI(12.88, 13.52)].

No meaningful interactions between inertial loads, exercise and training level were found [$F(6, 468) = 0.11$; $p = 0.99$; 95% CI(20.12, 13.35)].

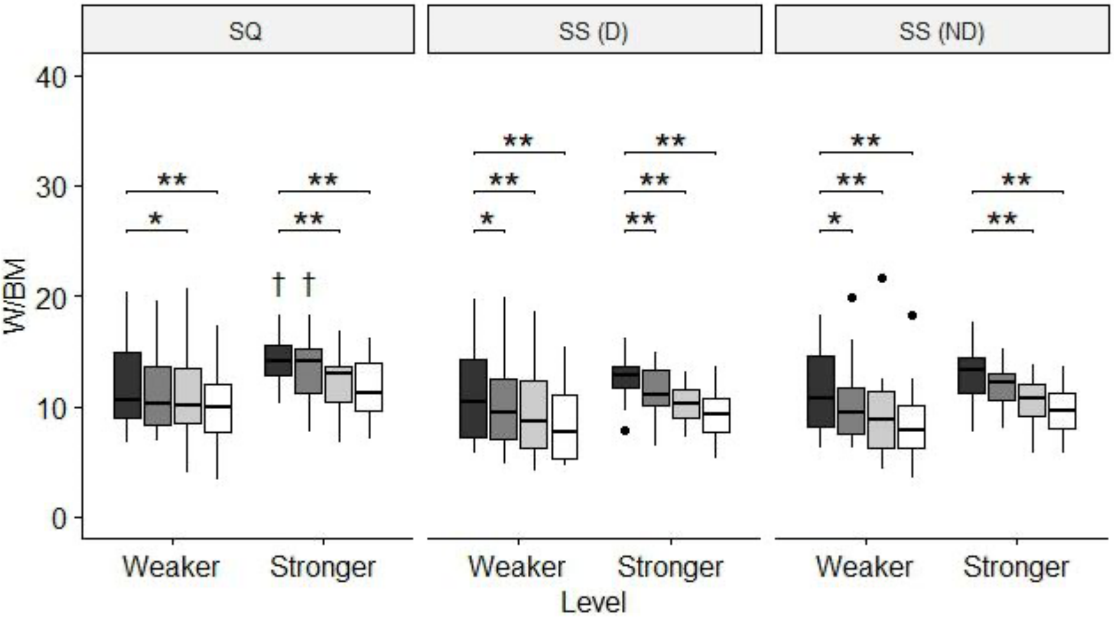

Figure 6. Inter-group comparison of inertias and concentric/body mass (BM) ratio in squat (SQ) and split squat (SS) dominant (D) and non-dominant (ND) exercises: *p <. 05; **$p < 0.01$; †meaningful differences between groups ($p < 0.05$). The different inertia values (1–4) are reported in different colors (black, dark grey, light grey and white), respectively.

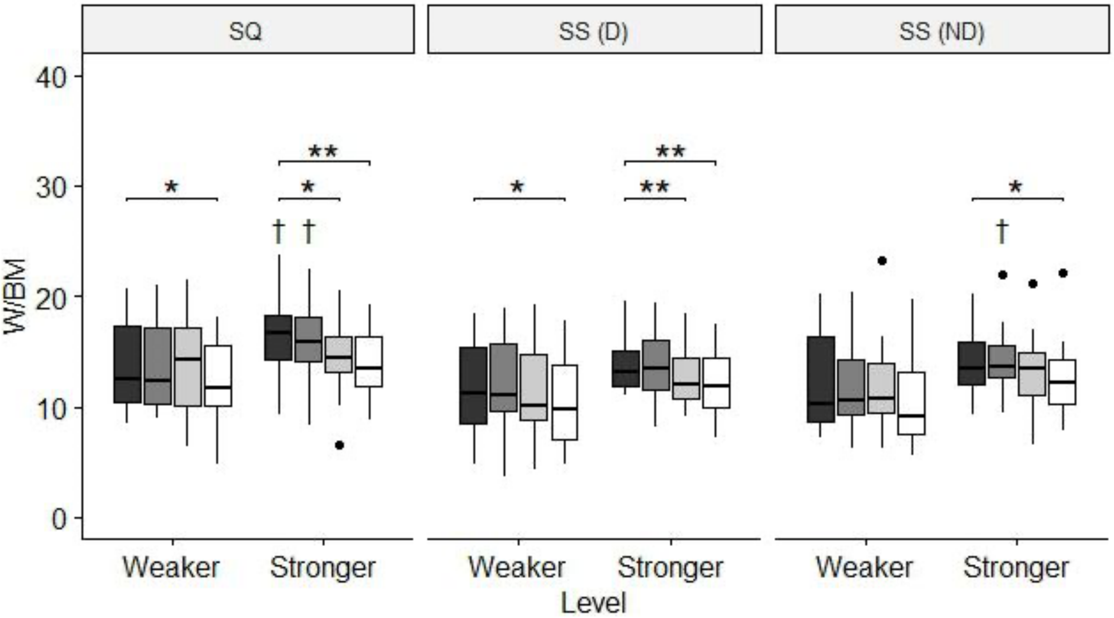

Figure 7. Inter-group comparison of inertias and eccentric/body mass (BM) ratio in squat (SQ) and split squat (SS) dominant (D) and non-dominant (ND) exercises: *$p < 0.05$; **$p < 0.01$; †meaningful differences between groups ($p < 0.05$). The different inertia values (1–4) are reported in different colors (black, dark grey, light grey and white), respectively.

DISCUSSION

The present study aimed to assess how mechanical outputs were affected by the subjects' BM, strength level, and type of exercise performed. The main findings of this research are: (1) in relation to EOL, the differences between squat and split squat exercises do not appear to be influenced by BM; (2) absolute power variables show differences in the concentric phase between inertial loads and there were also differences between exercises in the eccentric phase; (3) stronger subjects can achieve higher EOL values independent of the inertial loads used during a squat exercise; (4) weaker subjects can achieve greater EOL values with higher inertial loads; and (5) lighter inertial loads produce greater power outputs independent of the subjects' strength level (weaker and stronger group).

Flywheel resistance training can be very beneficial for improving hypertrophy, jump, power and strength performance (11, 28). However, there is a lack of evidence regarding how best to monitor and individualize training load variables with this technology. For instance, it is unclear how the variation of inertial loads can affect EOL with different exercises (23). Our results show EOL values increase as inertial load increases in bilateral squat (with significant changes only in the weaker group) and unilateral split squat exercises. Our findings are in line with previous research showing EOL increases when the load is greater. These results were seen in several exercises, such as the squat (24, 35), Romanian deadlift (30) and leg curl (31). However, there are also studies that found different results: for instance, in 2023 Muñoz-López et al. (26) found a trend for increases EOL with lower inertial loads; they also found higher EOL with low inertial loads (0.025 kg·m^2) compared to high inertial loads (0.125 kg·m^2). These results suggest that execution of the half squat compared to the quarter squat, could explain the difference in the relationship between EOL and load (35). Nevertheless, our study, and the previous one by McErlain-Naylor and Beato (24), found different results even though they used a half squat exercise. It is possible some differences exist in the literature because authors used participants with different strength levels, but these are not frequently reported. For instance, the characteristics of the participants enrolled in Muñoz-Lopez et al.'s study (25) could be similar to our stronger group. Therefore, future research investigating power–inertia relationships should also report the participant's strength level in order to facilitate comparison among studies.

Regarding PP_{conc} and PP_{ecc}, lower inertial loads showed greater power values for both exercises (i.e., squat and split squat with the dominant and non-dominant leg). These findings agree with previous studies that tested squat (25, 35), Romanian deadlift (30), leg extension (22) and leg curl exercises (31). However, no difference between inertial loads in PP_{conc} was reported in other studies (12, 24). McErlain-Naylor and Beato (24) found a similar pattern to our study for velocity and *PP* variables in the weaker group. However, the patterns for PP_{conc} and PP_{ecc} are very different in the stronger group with respect to the McErlain-Naylor and Beato study. The different number of repetitions during test situations in this study (eight repetitions) compared with the McErlain-Naylor and Beato (24) study (six repetitions) was proposed as a possible explanation for the difference in *PP* pattern. However, in addition to the results from analysis with eight repetitions, we also realized the same analysis with only the best three repetitions and no changes were obtained for any variable with respect to the analysis with eight repetitions. Possibly the strength level of the participants (not referenced in the McErlain and Beato study) was similar to our weaker group, where the differences in PP_{ecc} are lower between inertial loads. On the other hand, de Keijzer et al. (12) tested two unilateral open-chain movements, namely knee flexion and hip extension, and their results differed from our study. In the knee flexion exercise they did not find any change in PP_{con} or PP_{ecc} using three different inertial loads but increases were observed with higher inertial loads for the unilateral hip extension exercise. However, the values in study are higher compared to similar studies with the same movement such as Suarez-Arrones et al. (40), or , analized unilateral open-chain movement Martínez-Aranda et al. (22). It is important to indicate that the position and action of arms during movement (e.g. perpendicular position during Keijzer et al.'s studyor such a or Suarez-Arrones et al. where arms were located in the flywheel device). Another factor to consider is the possibility to stabilize the action with core activation or the opposite leg (difference between leg curl and hip extension in Keijzer et al.'s study, in contrast to Martínez-Aranda et al.'s study) can be key variables to explain the different profiles obtained by Keijzer et al. with respect to the majority of studies.

As previously stated, the three variables analyzed (EOL, PP_{con} and PP_{ecc}) showed a similar pattern in the squat and split squat exercises. EOL tends to increase with the inertial loads, whereas PP_{con} and PP_{ecc} tend to decrease with the inertial loads. However, two exceptions must be mentioned: the first isthe stronger group did not report any significant difference in EOL using any load during the squat exercise; the second is that PP_{ecc} in the split squat with the non-dominant limb did not show differences between inertial loads. Therefore, practitioners who want to employ unilateral movement in their training protocol should perform long familiarization periods with the non-dominant leg, as previously recommended (35).

To the authors' knowledge, this is the first study to report the effects of training level on flywheel squat and split squat variables. Our results show the stronger group has no differences between different inertial loads in squat exercise EOL values. Thus, stronger participants could train with any load to obtain an EOL, while weaker participants should preferentially train with higher inertial loads (0.075 or 0.100 kg·m^2) to obtain greater squat exercise EOL values. On the other hand, both weaker and stronger groups obtain the best EOL values for the split squat using higher inertial loads. Regarding PP_{con}, both groups obtained greater outputs with lower inertial loads (0.025 or 0.050 kg·m^2), so practitioners should preferentially use these inertial loads to maximize PP_{con} during training protocols. Nevertheless, when the target of the protocol is to maximize PP_{ecc}, a different profile can be observed on the basis of the subjects' training level. The weaker group obtained similar outputs using different inertial loads, which could be due to the difficulty for subjects to break the action during the eccentric phase (42). A comparison between two groups with different force production can be observed in Piqueras et al.'s (31) study, where men and women were analyzed during a leg curl exercise; however, in contrast to our results, similar profiles were obtained for both groups. De Keijer et al. (12) proposed the relevance of participant experience to obtain a good profile of EOL during different inertial loads. In our study, participants with similar previous experience can show different EOL profiles according to their relative strength (1RM squat/BM). Thus, it is the authors' opinion that relative strength is a key variable for programming flywheel resistance training because the strength level can influence velocity improvement (18).

Limitations and future directions

The present study has some limitations. First, no female subjects were included, so we cannot be sure whether these results could be applied to female populations. Future research should be carried out with other populations (elderly, young athletes, etc.) to verify the results of this study. Lastly, this study compared different exercises and inertial loads on mechanical power outputs but did not evaluate the benefits of the manipulation of training parameters on chronic adaptations. Future studies need to verify whether higher inertial loads are more suitable than lower inertial loads to generate neuromuscular and morphological adaptations, as well as whether unilateral exercises are more effective than bilateral exercises.

PRACTICAL APPLICATIONS AND CONCLUSIONS

The findings reported in this study can be useful for strength and conditioning coaches to optimize flywheel training protocols. The differences between squat and split squat exercises in EOL do not appear to be influenced by BM. Squat and split squat exercises present a different profile depending on the training level. The absolute power variables have shown differences in the concentric phase between inertial loads and also differences between exercises in the eccentric phase. Lighter inertial loads produce greater power output independent of group (weaker and stronger subjects). In conclusion, it is recommended that practitioner perform a test to understand the inertial load–power profile (concentric, eccentric and their ratio) for each exercise and also consider the user's strength level for selection of the inertial load as well as for the exercise to use in training.

ACKNOWLEDGMENTS

The authors are grateful to all the participants in the present study. This research was made possible by financial support from Grant PID2019-109632R8-100. Pablo Asencio's contribution was supported by the Spanish Ministry of Science and Innovation (Grant PRE2020-091858).

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APPENDIX 3.

Note. This study was published.

8.3 STUDY 3: Asencio, P., Hernández-Davó, J. L., García-Valverde, A., & Sabido, R. (2024). Effects of flywheel resistance training using horizontal vs vertical exercises. *International Journal of Sports Science and Coaching*, *19*(1), 410–416
https://doi.org/10.1177/17479541221135372

Appendix 3

Study 3: Effects of flywheel resistance training using horizontal vs vertical exercises

ABSTRACT

Flywheel resistance training is a very useful method to optimize athletic performance. However, research assessing the different loading conditions hypothesis during flywheel resistance training is scarce. The aim of this study was to assess the influence of the loading conditions used during flywheel resistance exercise on improvements in athletic performance. Twenty nine (29) athletes were randomly assigned to three different flywheel resistance training groups: vertical-directed exercises (VR), horizontal-direc- ted exercises (HR) and a mixed group (MIX). Performance assessment included one repetition maximum (1-RM) in the half-squat exercise, countermovement jump (CMJ) performance and change of direction (COD) ability (5-0-5 agility test). For the 1-RM squat, significant improvements were found in the VR ($p = 0.011$) and MIX groups ($p = 0.015$). All groups showed significant increases in CMJ height ($p < 0.05$), and significant decreases in 5-0-5 time with the non-dominant leg ($p<0.05$). As regards 5-0-5 with the dominant leg, the VR ($p = 0.004$) and MIX groups ($p = 0.001$) showed significant decreases in 5-0-5 time. Non-significant group × time interactions were noted. In conclusion, all groups showed similar improvements in 1-RM squat, jumping and COD performance. However, the inclusion of vertical-directed exercises seems to optimize increases in 1-RM squat.

Key words: *Change of direction, countermovement jump, eccentric overload, power, squat, strength.*

INTRODUCTION

Change of direction (COD) ability and jumping performance are considered crucial in many sports. Several authors have suggested that an increased COD ability is essential for successful participation in intermittent sports.[1,2] Some studies have supported this by using COD performance as a criterion for player selection in intermittent sports.[1,3] In the same line, jumping ability is a key variable in sports, as it is a decisive action in intermittent sports.[4–6] Consequently, improvements in both COD and jumping performance are one of the main goals of training programmes, especially during the pre-season, when strength and conditioning coaches have a greater time (e.g., 3–5 weeks) to develop players' physical qualities.[7]

There have been reports of increases in CMJ performance (e.g., jump height) after resistance training programmes using different methodologies, including traditional resistance training (e.g., free weights, stack machines),[8] plyometrics,[9,10] Olympic weightlifting movements,[11] isokinetic resistance training[12] and accentuated eccentric loading. In contrast, some of the above mentioned resistance training methods have failed to elicit improvements in COD performance,[13] possibly due to the type of exercise and the load used. A possible explanation for these findings is the relevance of the orientation of force application (e.g., vertical vs horizontal).[14,15] Despite the considerable number of articles evaluating changes in jumping performance, research assessing the influence of horizontal- versus vertical-directed resistance exercises on COD performance improvements is scarce. Gonzalo-Skok et al.[16] examined the influence of vertical- and horizontal-directed plyometric training on COD performance (e.g., "V" cut test) in intermittent sports players, showing no significant differences between the two training methods, while Ramirez-Campillo et al.[17] suggested a mixed method (i.e., a combination of horizontal- and vertical-directed plyometric exercises) as the most appropriate to improve COD performance.

The pre-season period allows for a greater amount of time and focus to be dedicated to improving physical performance (jump and COD performance).[18] In the last few decades, flywheel resistance training has emerged as a useful strategy not only to promote muscular hypertrophy and strength gains,[14] but also to increase athletic performance, including COD and jumping performance.[19] When performing the movement correctly, flywheel devices allow for brief episodes of the so called "eccentric overload", that is, greater force or power values in the eccentric phase than the concentric phase are produced.[14] Some researchers have suggested that this eccentric overload provides a great mechanical stimulus for both the muscular and tendinous tissues[19] which benefits early neuromuscular (e.g., strength and power increases) and performance (e.g., jumping and COD ability) adaptations. In addition, flywheel devices allow the performance of highly specific and multiplanar exercises, which better replicate the actions found in sporting environments.[20,21] However, in spite of the previous promising performance improvements following flywheel resistance training methods, research assessing the influence of force orientation during flywheel exercise is limited. Therefore, the aims of the present study were (1) to assess the usefulness of different loading conditions (i.e., vertical, horizontal, and mixed) during different flywheel exercises on squat strength gains, vertical jump increases and COD performance, and (2) to check if adaptations in these variables differed depending on the loading conditions used. It is hypothesized that the strength gains will be specific to the loading conditions used in training.

METHODS

Participants

Thirty-three male recreational athletes (age = 23.40 ± 5.34 years; height = 1.77 ± 0.07 m; body mass = 75.35 ± 13.96 kg) from different intermittent sports (e.g., football, futsal, tennis, and basketball) took part in the study. Although all participants reported at least 12 years' experience in their respective sports, they were not familiar with flywheel resistance training. All participants were following a three days/week specific on-court training regime in their sport, but at the time of the study, they were not involved in any strength programme. Before participating, each participant provided written informed consent in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University. According to the aim of the study, participants were stratified based on their 1RM/ body mass strength and randomly assigned to one of the three different flywheel resistance training programmes, using these vertical-directed exercises (VR group, n = 11; 22.6 ± 4.0 years; 1.79 ± 0.09 m; 75.5 ± 14.1 kg), horizontal-directed exercises (HR group, n = 8; 22.0 ± 4.1 years; 1.76 ± 0.05 m; 74.9 ± 11.4 kg) or a mix of vertical- and horizontal-directed exercises (MIX group, n = 10; 24.9 ± 6.3 years; 1.77 ± 0.09 m; 75.6 ± 16.8 kg). A priori statistical power of the sample was calculated (power 0.8, $p < 0.05$, CI = 95%), indicating that 30 participants were required. Initially, all groups included 11 participants, but during the study, a total of four participants dropped out, being three from the HR group and one from the MIX group. These drop outs were not related to injuries nor to reasons related to the study.

Before testing, all participants completed two familiarization sessions with the flywheel exercises, where they performed two sets of 10 repetitions in each exercise: squat, horizontal split squat, vertical split squat, and lunge. In addition, these familiarization sessions to practise all tests (i.e., 5-0-5, CMJ and squat strength). At least three days apart from the second familiarization session, participants com- pleted a testing session comprised of the 5-0-5 test, CMJ and 1-RM squat. This same testing session was repeated one week after the training intervention.

COD performance test

The ability of participants to perform a single and rapid 180° COD over 5 m was evaluated using a modified version (stationary start) of the 505 test[20] Participants started in a standing position with their preferred foot behind the starting line, followed by accelerating forward at maximal effort until reaching a line placed at 5 m. Two trials pivoting on both dominant (i.e., preferred kicking leg) and non-dominant leg were completed, and the fastest time recorded by means of a contact platform (Chronojump Boscosystem, Barcelona, Spain) was used for analysis. Two minutes of rest was allowed between trials. This test showed an intraclass correlation coefficient (ICC) of 0.87, a coefficient of variation (CV) of 3.4%, and a smallest worthwhile change (SWC) of 0.05 s.

Jumping performance test

A bilateral CMJ without arm swing were performed in a contact platform (Chronojump Boscosystem). Participants performed the jumps starting in a standing position with their hands in their hips; they flexed their knees using a self-selected depth and then jumped as high as possible. Each participant performed five maximal CMJs interspersed with 45 s of passive recovery. The best and worst of the trials were eliminated, and the three remaining jumps were averaged. The ICC for this test was 0.955, with a CV of 3.4%, and a SWC of 1.08 cm.

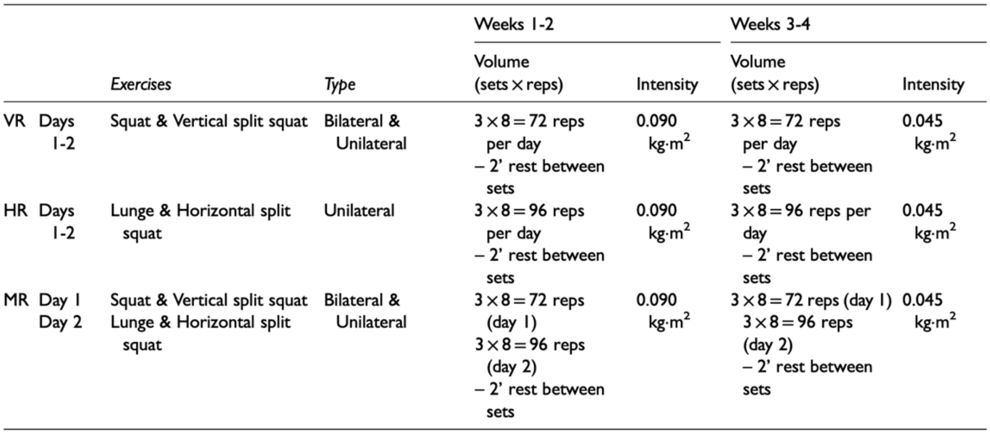
Maximum dynamic strength test

The 1-RM test was carried out using a linear position transducer (Chronojump Boscosystem), which recorded the bar position with an analogue-to-digital conversion rate of 1000 Hz. A specialized software application (Chronojump Boscosystem version 1.8.1) automatically calculated the relevant kinetic and kinematic parameters.[22] For the 1-RM estimation, participants started from a shoulder width stance apart and the barbell resting on the upper back, approximately at the level of the acromion, with the knees and hips fully extended. Each participant descended until their thighs were parallel to the ground and subsequently, ascended to the upright position. Participants started with an absolute load representing 50% of their body mass and, thereafter, the load gradually increased until the mean propulsive velocity was $< 0.5\ \text{m}\cdot\text{s}^{-1}$. Using this submaximal load, participants performed three maximal-intended repetitions and the specialized software of the linear position transducer automatically estimated the 1-RM. Several studies have supported the use of movement velocity for 1-RM estimation.[22] Rest interval between sets was set at 3 min.

Training programmes

One week after the pre-test, participants started a 4-week flywheel resistance training intervention using a conical pulley device (VersaPulley, Iberian Sportech, Sevilla, Spain). All three groups performed two training sessions per week, with an equated training volume (i.e., two exercises, three sets of eight repetitions each session). After a standardized warm up, every group performed one set of eight reps of 5-0-5 test at maximum speed with 30 s of rest between repetitions. On the other hand, before of flywheel training, subjects did three sets and four repetitions of SJ (weeks 1 and 2) and CMJ (weeks 3 and 4) with the 30% of 1-RM. The inertial load used for flywheel training was 0.090 kg·m^2 during the first two weeks, and 0.045 kg·m^2 during weeks three and four, while the widest part of the conical pulley was selected for the strap rewind height aiming to maximize movement velocity.[23] This programming approach was used to combine different inertial loads, which has been proposed as optimal to improve athletic performance.[23,24] The training programmes differed based on the exercises performed, which emphasized either horizontal (HR group) or vertical-directed force (VR group), or a combination of both (MIX group). During all training sessions participants were fully encouraged to perform the concentric action as fast as possible and to delay the braking phase to the last part of the eccentric action, which facilitate the achievement of eccentric overload. Table 1 shows the schedule of the study and the exercises used in each training group.

Table 1. Summary of the study design and exercises performed by each group.



				Weeks 1-2		Weeks 3-4	
		Exercises	*Type*	Volume (sets × reps)	Intensity	Volume (sets × reps)	Intensity
VR	Days 1-2	Squat & Vertical split squat	Bilateral & Unilateral	3 × 8 = 72 reps per day – 2’ rest between sets	0.090 kg·m^2	3 × 8 = 72 reps per day – 2’ rest between sets	0.045 kg·m^2
HR	Days 1-2	Lunge & Horizontal split squat	Unilateral	3 × 8 = 96 reps per day – 2’ rest between sets	0.090 kg·m^2	3 × 8 = 96 reps per day – 2’ rest between sets	0.045 kg·m^2
MR	Day 1 Day 2	Squat & Vertical split squat Lunge & Horizontal split squat	Bilateral & Unilateral	3 × 8 = 72 reps (day 1) 3 × 8 = 96 reps (day 2) – 2’ rest between sets	0.090 kg·m^2	3 × 8 = 72 reps (day 1) 3 × 8 = 96 reps (day 2) – 2’ rest between sets	0.045 kg·m^2

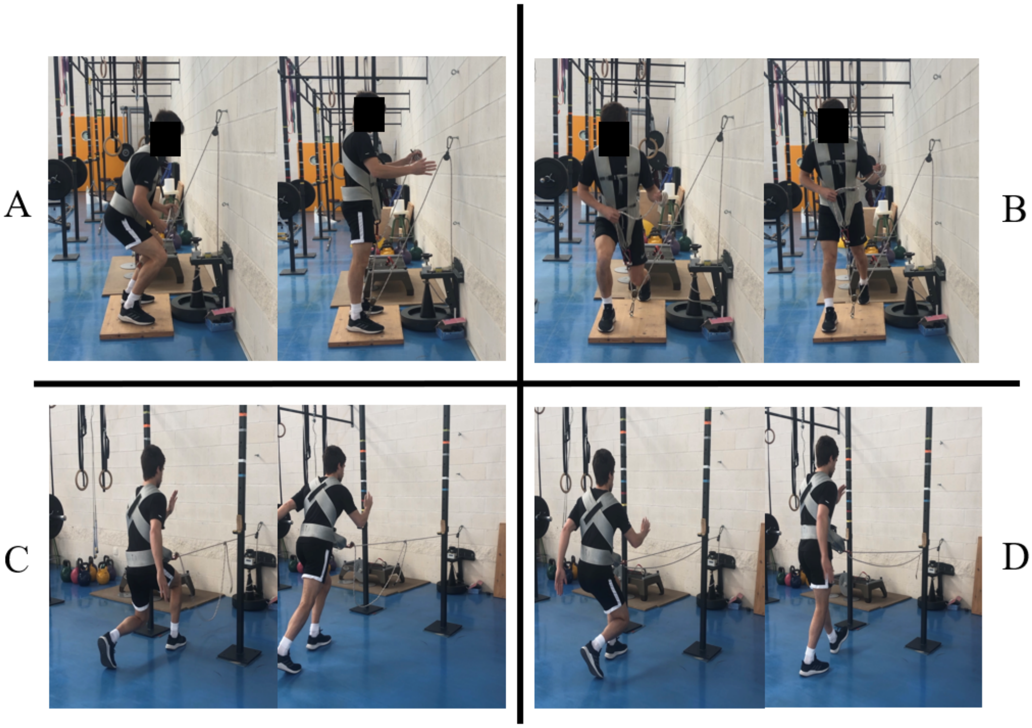


Figure 1. Exercises used during the flywheel resistance training program. The VR group used exercises A and B, the HR group used exercises C and D, while the MIX group used all.

Statistical analysis

All statistical analysis were performed using the SPSS statistical package version 25.0 (IBM, New York, NY, USA). After confirming data normality using the Kolmogorov-Smirnov test, the effectiveness of each program (VR, HR, and MIX) was assessed using a 3 (VR, HR, and MIX)×2 (pre and post) mixed ANOVA was used. If needed, a Bonferroni post hoc test was used for pairwise comparisons. Statistical significance was set at $p < 0.05$. In addition, Cohen's d effect size (ES) was calculated to assess the magnitude of changes, being interpreted as trivial (< 0.2), small (0.2-0.5), moderate (0.5– 0.8) and large (> 0.8).

RESULTS

There was a main effect ($p < 0.001$) for time in all the performance variables. However, no group × time interactions were found in 1-RM ($p = 0.309$), CMJ ($p = 0.956$), 5-0-5 D ($p=0.730$) and 5-0-5 ND ($p = 0.282$). Table 2 shows all pre- to post-changes in performance variables. For the 1-RM squat, significant improvements were found in the VR ($p=0.011$) and MIX groups ($p = 0.015$), and a trend for significance in the HR group ($p = 0.093$). All groups showed significant increases in CMJ height ($p < 0.05$). Regarding 5-0-5 with the dominant leg, both the VR ($p = 0.004$) and the MIX groups ($p = 0.001$) showed significant decreases in 5-0-5 time, while the HR group showed a non- significant trend for 5-0-5 time decrease (p = 0.066). For the 5-0-5 with the non-dominant leg all groups showed significant decreases in 5-0-5 time (p < 0.05).

Table 2. Pre- to post-changes in strength, jumping and COD performance by group.

	VR				HR				MIX				
Variable	Pre	Post	*p*	ES	Pre	Post	*p*	ES	Pre	Post	*p*	ES	*p* (time*group)
1-RM squat (kg)	91.3 ± 13.0	98.9 ± 13.7	0.011	0.57 (0.23, 0.86)	93.0 ± 13.6	96.5 ± 15.2	0.093	0.24 (0.01, 0.45)	94.4 ± 17.6	103.9 ± 17.1	0.015	0.55 (0.25, 0.85)	0.309
CMJ (cm)	32.6 ± 3.9	35.5 ± 3.8	0.001	0.75 (0.46, 0.92)	32.0 ± 3.2	35.0 ± 5.2	0.047	0.69 (0.05, 1.33)	34.0 ± 4.4	36.7 ± 4.5	0.006	0.61 (0.33, 0.90)	0.956
5-0-5 D (s)	2.70 ± 0.22	2.45 ± 0.23	0.004	1.11 (0.57, 1.63)	2.76 ± 0.32	2.55 ± 0.26	0.066	0.72 (−0.02, 1.42)	2.58 ± 0.21	2.36 ± 0.12	0.001	1.29 (0.92, 1.66)	0.730
5-0-5 ND (s)	2.68 ± 0.22	2.43 ± 0.17	0.009	1.27 (0.66, 1.88)	2.71 ± 0.26	2.35 ± 0.13	0.006	1.75 (1.12, 2.37)	2.59 ± 0.23	2.42 ± 0.18	0.014	0.82 (0.39, 1.25)	0.282

CMJ = countermovement jump; D = dominant; ND = non-dominant; 1-RM = one repetition maximum.

Table 3. Between-group differences (ES) in the performance changes.

Variable	VR vs HR	VR vs MIX	HR vs MIX
1 RM	0.32 (−0.09, 0.72)	−0.10 (−0.52, 0.31)	−0.34 (−0.71, 0.03)
CMJ	0.01 (−0.55, 0.56)	0.08 (−0.27, 0.42)	0.07 (−0.46, 0.60)
505 DOM	0.07 (−0.84, 0.97)	−0.24 (−0.90, 0.42)	−0.22 (−1.03, 0.59)
505 NDOM	−0.44 (−1.29, 0.42)	0.32 (−0.39, 1.03)	0.70 (−0.03, 1.42)

Note: A positive value indicates a greater adaptation for the first group of the comparison.

The ES values for between-group comparisons are shown in Table 3. Despite the lack of group × time interactions, VR and MIX groups showed greater improvements in 1-RM, although of small magnitude (ES = 0.32–0.34), than the HR group. For 5-0-5 ND the HR group showed greater performance increases of small (ES=0.44) and moderate (ES=0.70) magnitude than the VR and the MIX group respectively. In addition, HR group showed slightly greater improvements (of small magnitude) than the VR (ES = 0.24) and MIX (ES = 0.22) group.

DISCUSSION

The aim of the present study was to assess the influence of the different loading conditions used during flywheel training (i.e., vertical, horizontal, and mixed) on squat strength gains, vertical jump increases and 5-0-5 completion time. The main finding of the present study is that in recreational athletes, the improvements in performance variables are not significantly different when comparing the three training approaches. However, the group that trained using horizontal-directed exercises was the only not reaching significant improvements in 1-RM squat.

Studies have linked maximal strength levels in the squat exercise to improved sprinting and decreased 5-0-5 comple- tion time.[25,26] In the present study, despite the non-significant time × group interactions, within group changes showed that both VR and MIX groups significantly improved their 1-RM squat, while the HR group did not show a statistically significant increase. In addition, between-group comparisons showed small greater improvements (ES = 0.32–0.34) in both VR and MIX groups compared with the HR group. This is in line with Contreras et al.,[27] who reported that a vertical-directed exercise (e.g., squat) was possibly more effective in increasing 1-RM squat strength than a horizontal-oriented exercise (e.g., hip thrust). However, it should not be discarded that the improvements in VR and MIX groups are partially caused by similarities between the training exercises (flywheel squat) and the testing exercises (free weight squat). These results are of significant practical application, as increases in 1-RM squat during pre-season periods have been previously linked to improvements in sprint performance.[28] As both VR and MIX groups performed the flywheel squat exercise during training, the present results confirm the widely reported usefulness of this exercise in improving 1-RM strength.[20] Despite part of these improvements may be attributed to the sample training status (e.g., recreational players), it should be highlighted that previous research using flywheel devices used longer training programs (e.g., 5–12 weeks). Therefore, it should be highlighted that the present study showed these improvements after a 4-week training program, which match with the habitual duration of the team-sports pre-season and could therefore be used by strength and conditioning coaches.

A recent meta-analysis[14] has shown the positive effects of flywheel resistance training in CMJ height increases. However, to date, no research has assessed whether the use of different vector-directed flywheel resistance exercises leads to distinct CMJ increases. The improvements in CMJ found in the three different groups were almost identical (about three centimeters in each group), with all showing ES of moderate magnitude and similar increases of 2.7 cm (MIX), 2.9 cm (VR) and 3.0 cm (HR). Further, between-group comparisons showed trivial differences when comparing all training groups (ES < 0.1). This is in line with previous studies reporting similar increases in vertical jump performance after plyometric training using either vertical or horizontal exercises,[10] or mixed vertical and horizontal exercises in recreational athletes of intermittent sports.[17] Moran et al.[15] confirmed this idea in a recent meta-analysis in which force direction in plyometric exercises had no relevance to improving CMJ. While Contreras et al.[27] suggested vertical resistance exercise as possibly most appropriate to improve vertical jump performance, other authors have shown the efficacy of horizontal exercises (e.g., hip thrust) in improving CMJ performance.[29] In addition, Gonzalo-Skok et al.[30] reported similar significant improvements in CMJ performance after a flywheel training intervention in both vertical and multi-directional training groups. It can be hypothesized that the exercises considered as horizontal induce a positive effect in vertical jump performance, likely by their similar movement patterns to the CMJ, including knee and hip extension. Thus, it is possible to consider the selection of either horizontal, vertical, or mixed flywheel exercises as suitable when aiming to improve CMJ performance in recreational athletes.

The importance of COD actions in many sports explain the necessity to find training interventions leading to improve this ability. Flywheel resistance training have been suggested as an optimal stimulus for improvements in COD ability,[20] being even more effective than traditional resistance training in improving this ablity. In agreement with this, all groups in the present study showed significant reductions in 5-0-5 completion time, the improvements being of moderate to high magnitude (see Table 2). Despite some authors suggesting that different vector- directed exercises may lead to distinct performance adaptations, the current study shows that all training groups simi- larly improved COD performance. Although the mangitude of changes showed by the HR group were slighlty higher compared with both VR and MIX group, these changes did not reach statistical significance. This is in line with previous research using plyometric[10,16] and flywheel training,[20] where similar improvements in COD performance were found in both vertical and horizontal groups. Improvements in 5-0-5 performance in the current study (7–10%) were higher than the improvements reported by Manouras et al.[10] (3–4%) and Gonzalo-Skok et al.[16] (3%), which can be explained by the lower level and the relatively limited resistance training background of the participants in the current study. Again, the results of the present study support the inclusion of flywheel resistance training when aiming to improve COD ability.

The present study is not without limitations. The characteristics of the sample, with limited resistance training experience, favoured the significant improvements found in all groups. Further, the relatively small sample size and the lack of a control group limit the conclusions of the study. Future studies are required to assess whether the influence of vertical, horizontal or mixed exercise selection during flywheel training leads to distinct performance adaptations in athletes with higher resistance training experience. Other factors such as the slight difference in training volume (e.g., repetitions per session) and exercises type (bilateral vs unilateral) may have also affected the results of the present study. In addition, training intervention comprised eight training sessions (i.e., 4 weeks – 2 sessions/week), which might be insufficient to find differences between the training groups. However, due to limited time available during pre-season periods in most sports (e.g., handball, football, basket- ball), the present study design is in line with the real sports calendar, and therefore represent a possible training scenario.

PRACTICAL APLICATION

Flywheel resistance training, in spite of the different loading contitions (e.g., vertical or horizontal exercises) is highly effective in improving 1-RM squat strength, CMJ performance and COD ability. Strength and conditioning coaches should be aware that, both VR and MIX, but not HR group, showed improvements in 1RM squat (with moderate ES). Thus the inclusion of vertical-directed exercises is recommended when aiming to optimize 1-RM squat increases. There were no apparent differences between either horizontal-, vertical-directed, or a combination of horizontal and vertical-directed flywheel exercises in promoting improvements in, jumping and COD performance. Of note is that improvements in jumping and COD perform- ance were visible after a short-term (i.e., four weeks) training intervention. Due to the congested calendar of most team-sports, with pre-season periods of approximately 4 weeks, this study highlights flywheel resistance training as a powerful stimulus to achieve performance adaptations in such periods.

ACKNOWLEDGEMENTS

No financial support was received to carry out this study.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FUNDING

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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APPENDIX 4.

Note. This study was published.

8.4 STUDY 4: Asencio, P., Moreno, F. J., Hernández-Davó, J. L., & Sabido, R. (2024). Effects of variable intensity and constant intensity flywheel resistance training programs on specific soccer players' performance. *Frontiers in Physiology*, 15. https://doi.org/10.3389/fphys.2024.1375438

Appendix 4

Study 4: Effects of variable intensity and constant intensity flywheel resistance training programs on specific soccer players' performance

ABSTRACT

Resistance training programs play a crucial role in optimizing soccer performance. The aim of this study is to compare performance outcomes in sport-specific tasks after implementing two different flywheel resistance training (FRT) programs: variable intensity (VI) and constant intensity (CI). Seventeen ($n = 17$) amateur footballers were divided into VI and CI groups with the same training volume. For the VI group, a decrease in inertial load was implemented every four sessions, whereas the CI group maintained a constant load during the entire program. After different familiarization sessions and testing (sprint, change of direction, jump, one-repetition maximum and flywheel strength variables), eleven sessions of FRT were performed over five weeks. Both groups showed similar improvements in the one-repetition maximum ($p < 0.01$) but the CI group had significant improvements in the 10-m sprint ($p = 0.04$; ES = 0.72), emphasizing the potential benefits of medium inertial loads to maximize power and specificity in sport tasks. However, no significant differences were observed in the countermovement jump, change of direction and 30-m sprint, possibly attributed to neuromuscular fatigue from a high-volume training schedule and friendly matches. The study highlights the importance of considering training load distribution in FRT programs. The findings emphasize the need for complementary training to maximize the jump and change of direction abilities and caution against high-volume training and friendly match scenarios. In conclusion, FRT programs, whether varying in intensity or not, can yield medium-term performance improvements for soccer players.

Key words: *flywheel resistance training; soccer; training program; strength training; performance.*

INTRODUCTION

Resistance training programs should consider various training variables over time (1) and there are different programming strategies to optimize the force–time relationship and consequently increase performance in sport-specific tasks (2). For this reason, programs should thoroughly control variables such as intensity, volume, density, frequency or exercise selection (3). Training volume and training intensity have received the greatest attention in strength training programs. Intensity can be expressed as a percentage of the one-repetition maximum (1RM), velocity of the bar, repetitions in reserve or rating of perceived effort (RPE) (4). On the other hand, training volume is represented by the total session workload performed, which influences the magnitude of metabolic stress and muscle damage (5). Intensity and volume manipulation dictate the physiological and biomechanical resistance training demands. Therefore, a combination of training variables is essential for optimizing training outcomes, achieving fitness goals and reducing the risk of overtraining (6).

Over the last few years, flywheel resistance training (FRT) has gained a lot of relevance in the world of strength and conditioning (7). This technology involves the use of a rotating mass that stores and releases energy during exercise (8). Furthermore, practitioners can maximize the training effect of flywheel resistance technology by generating greater eccentric than concentric power outputs, a phenomenon referred to as eccentric overload (9). In addition, flywheel devices offer the possibility of performing specific and multi-planar exercises, replicating sport actions (10). These characteristics have caused flywheel technology to be widely used in sports, most commonly in football (11). Research has proven the effectiveness of FRT in enhancing strength (10, 12), power (10, 12), change of direction (COD) (13, 14), countermovement jump (CMJ) (12) and sprint performance (15). In addition to the classical training variables, FRT requires the management of other variables, such as strap rewind height (16), rope length (16) and loading conditions (17).

Despite the effectiveness of FRT at improving athletes' performance, supported by previous research (11), only a few programming variables (mainly intensity/inertial load) have been studied in the scientific literature. This scarcity of research signifies a lack of knowledge about the optimal manipulation of basic variables during an FRT program. Most studies (15, 18, 19) used a constant load approach (same inertial load during FRT), finding improvements in different performance variables such as the CMJ, sprint performance or 1RM squat. To the authors' knowledge there is only one study (20) that compared the effect of FRT on performance variables in rugby players who were divided into two training groups with different intensity during the intervention (0.075 $kg \cdot m^2$ and 0.025 $kg \cdot m^2$, respectively). The study reported 1RM squat and CMJ improvements in both groups but no improvement in COD and a possible decrease in sprint performance at 0.075 $kg \cdot m^2$. However, for the 0.025 $kg \cdot m^2$ group there were small changes in linear sprint and positive effects on the agility T-test. Recently, Beato and colleagues (2021) proposed methodological bases of flywheel periodization in team sports and the distribution of training variables along the microcycle. Nevertheless, there is a need to compare the effect between different types of FRT programs in medium- and long-term adaptations.

Due to the lack of research on the possible effects of different FRT programs, it is important to determine whether a change of training intensity over time is needed during an FRT program. The objective of this study is to compare two types of training programs in sport performance tasks: variable intensity (VI) and constant intensity (CI). We hypothesized that varying the intensity is necessary to achieve medium-term performance adaptations and, consequently, that the VI group will achieve higher levels of performance than the CI group.

MATERIALS AND METHODS

Study design

This experimental study was carried out during seven weeks of the pre-season period (see Table 2). In Weeks 1 and 7, performance assessments were performed. After a familiarization procedure and testing, participants were divided into two groups differing in the type of intensity distribution (VI and CI). For the VI group, inertial load was changed from higher to lower (see Figure 1), whereas for the CI group, the inertial load was constant during all training periods. Both groups trained with the same density and total volume.

Participants

Seventeen (n = 17) amateur footballers in the Spanish third division team took part in this study. Participants had at least two years of experience in resistance training. Previous power analysis was conducted to determine the appropriate sample size using G* Power (version 3.1.9.3, Düsseldorf, Germany). According to the study design (2 groups, 2 repeated measures), a medium effect size f = 0.8, a correlation between measurements of $r = 0.6$, an $\alpha = 0.05$, a required power $1\text{-}\beta = 0.95$, a sample of 16 participants was required (actual power = 0.95).

Participants were assessed for their 1RM and subsequently assigned to one of two homogeneous groups according to player's role and strength level based on their 1RM/body mass (21).

The VI group (n = 8; age = 22.00 ± 5.71 years; height = 1.82 ± 0.08 m; body mass = 76.20± 6.40 kg; 1RM = 132.48 ± 18.90; ratio 1RM/body mass = 1.74 ± 0.29) trained with decreasing inertial load every four training sessions (0.12 $kg{\cdot}m^2$; 0.10 $kg{\cdot}m^2$; 0.08 $kg{\cdot}m^2$) and the CI group (n = 9; age = 22.9 ± 7.2 years; height = 1.80 ± 0.04 m; body mass = 75.66 ± 6.13 kg; 1RM 130.41 ± 19.87 kg; ratio 1RM/body mass 1.80 ± 0.04) trained with 0.08 $kg{\cdot}m^2$ during the entire training period. Participants provided written informed consent in accordance with the Declaration of Helsinki and the study was approved by the ethics committee of the host institution (Code: ADH.DES.RSS.PAV.23).

Procedures

During the first week, participants were tested on three separate sessions, with 72 h of recovery between sessions. On the first day, descriptive (e.g. age, training level) and anthropometric data were recorded for each participant. After that, jump tests and a 1RM back-squat test were performed and participants completed a flywheel familiarization protocol (16). On the second day, participants conducted speed and COD tests and another flywheel familiarization protocol. On the last day, a flywheel squat exercise test was performed (see Figure 1).

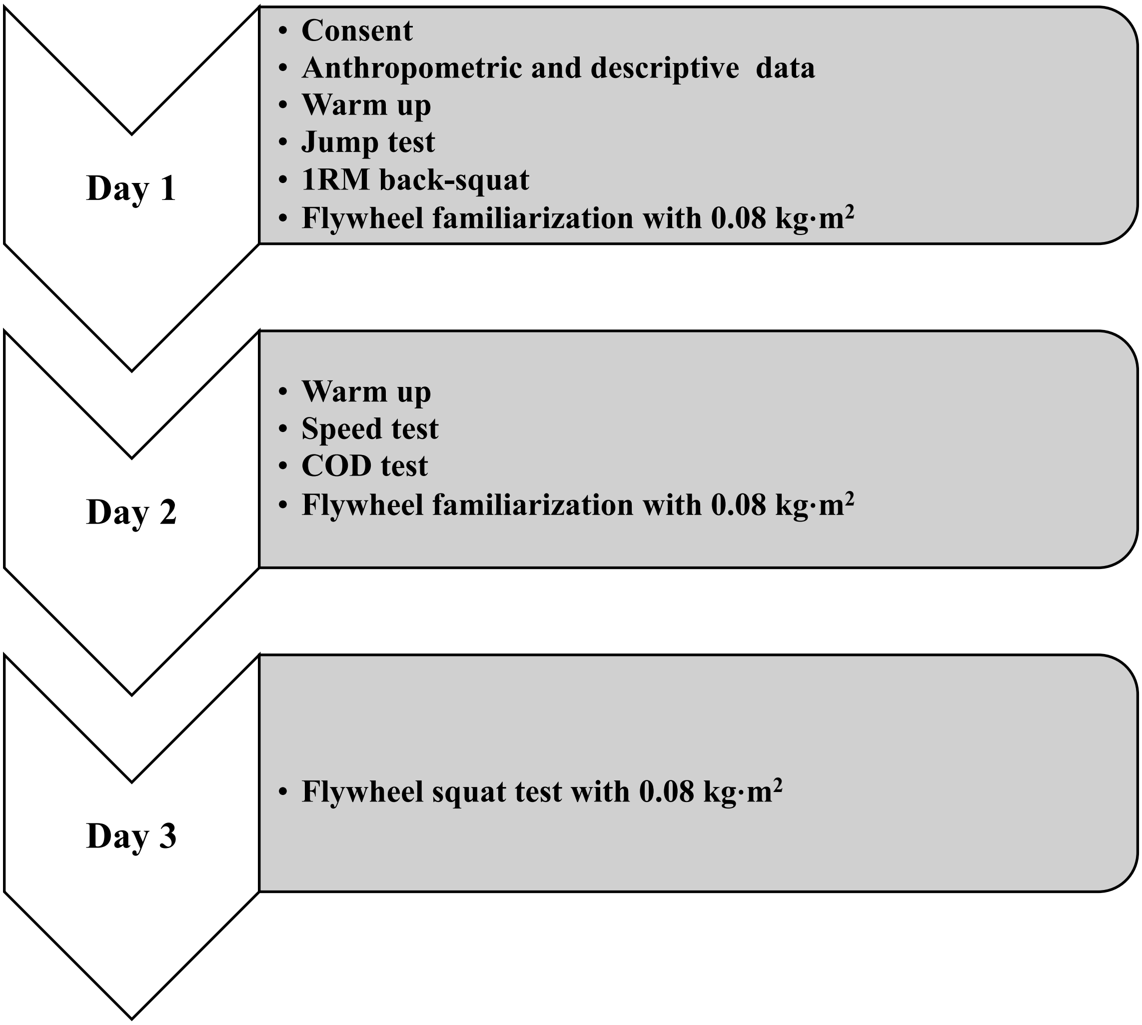

Figure 1. Scheme of the pretest.

Testing Session 1: CMJ and 1RM

Data on the CMJ and 1RM back-squat test were collected from the participants. A contact platform (Chronojump Boscosystem) was used to assess the CMJ. Participants were instructed to achieve their maximum jump height, with hands on their hips, and to execute the descending phase at their preferred depth. Three attempts were assessed and the best trial was used for analysis.

Data on the 1RM back-squat exercise were obtained using a linear encoder (T-Force System, Ergotech, Murcia, Spain) and a software application was used to calculate the relevant kinetic and kinematic parameters. For 1RM estimation, participants performed a protocol previously described by Loturco et al. (22). Briefly, this consisted of starting from a shoulder-width stance with the barbell positioned on the upper back near the acromion and with the knees and hips fully extended. Each participant descended until the thighs were parallel to the ground and then they ascended to an upright position. Participants started with a load representing 50% of their body mass and thereafter the load was gradually increased until the mean propulsive velocity was < 0.5 m·s. Using this submaximal load, participants performed three maximal repetitions and with the linear position transducer attached it was possible to automatically estimate the 1RM of the athletes. A 4-min rest interval separated each test and the 1RM was estimated based on movement velocity, as previously described.

Testing Session 2: Speed and COD

Acceleration, speed capacity and COD were evaluated on a grass soccer field. To assess speed, the 10-m sprint and 30-m sprint were performed. Participants stood 1 m behind the start line in a starting position with the body leaned forward. Timing gates (Microgate, Bolzano, Italy) were placed at the start (0 m), middle (10 m) and end (30 m), with reflectors at 1 m height (23). Participants were instructed to sprint at maximum speed for the entire distance. Each participant performed three attempts, with 2 min of passive recovery. The best score was used for the analyses.

COD was tested using the modified 505 test (M505), which involved two attempts of a 5-m sprint followed by a 180º COD and return to the starting point, which is a common maneuver in many sports (10). Timing gates (Microgate, Bolzano, Italy) were positioned at the starting and finishing points. Tests started on the "Go" command from a standing position, with the front foot 0.2 m from the photocell beam (25).

Testing Session 3: Flywheel squat

On the last testing day, participants completed a flywheel squat test with the flywheel device (VersaPulley, Iberian Sportech, Seville, Spain), carrying out a maximum set of eight repetitions, with an additional two initial repetitions needed to build momentum. The inertial load used during the test was 0.08 kg·m^2. Participants performed two sets to warm up with a 2-min rest interval, a protocol recommended by Sabido et al. (2017). During each repetition the concentric and eccentric power (and their ratio) were recorded using a linear encoder and subsequently analyzed (SmartCoach Power Encoder, Europe AB, Stockholm, Sweden). The variables used for data analysis were peak concentric power (PP_{con}), peak eccentric power

(PP_{ecc}) and the eccentric overload (EO) ratio.

Training program

One week after the pre-test, participants started the training program using a flywheel device. Both groups engaged in two training sessions per week. The total volume of the training program was equated and the widest part of the conical pulley was chosen for setting the strap rewind height, aiming to maximize movement velocity (16) (see Table 1). The program consisted of two exercises with different force vectors (vertical squat and horizontal lunge; see Table 1) twice a week. After a general warm up, each training session encompassed flywheel resistance exercises and a general soccer injury prevention program (e.g. core stability, balance and proprioceptive and hamstring eccentric exercises; see Table 2). During each set, two initial repetitions were needed to build inertia momentum and participants were instructed to perform each repetition as fast as possible and to delay braking action until the last third of the eccentric phase (20). Rest intervals were standardized at 2 min, as specified by Sabido et al. (18). The training protocols exhibited variations in training intensity, with a focus on either a conventional training block from high to low loads (G1) or constant load (G2) approaches (see Table 1). After Week 6, participants completed the post-test procedure.

Table 1. Training volume and intensity for the two groups. CI: constant intensity; VI: variable intensity; S: sets; R: repetitions; T: total repetitions.

				SQUAT			**HORIZONTAL LUNGE** (total sets)		
CI GROUP	**VI GROUP**			**S**	**R**	**T**	**S**	**R**	**T**
Inertia *0.08 kg·m^2*	**Inertia** *0.12 kg·m^2*	**Week 1**	***Session 1***	3	6	18	2	6	12
			Session 2	3	6	18	4	6	24
		Week 2	***Session 3***	4	6	24	4	6	24
			Session 4	4	7	28	4	6	24
	Inertia *0.10 kg·m^2*	**Week 3**	***Session 5***	4	8	32	4	8	32
			Session 6	4	8	32	4	8	32
		Week 4	***Session 7***	4	8	32	4	8	32
			Session 8	4	8	32	4	8	32
	Inertia *0.08 kg·m^2*	**Week 5**	***Session 9***	4	8	32	4	8	32
			Session 10	4	11	44	4	11	44
						292			**288**
								T:	**580**

Table 2. Weekly training plan for the training period. LSG: long side games; MSG: medium side games; SSG: small side games.

	Monday	*Tuesday*	*Wednesday*	*Thursday*	*Friday*	*Saturday*	*Sunday*
Week 1		Testing	Testing	Strength exercises technique LSG – MSG 2x (5vs5) + 3	Strength exercises technique LSG (11vs11) 3x12’	REST	REST
Week 2	AM: Testing PM: Flywheel training – Injury prevention SSG-MSG (7vs7) 4x8’	LSG (11vs11) 3x12’ Upper body strength work	AM: Flywheel training – Injury prevention PM: Friendly match	Upper body strength work	LSG – MSG 2x12’	Friendly match	REST
Week 3	AM: SSG – MSG 4x6’ PM: Flywheel training – Injury prevention	LSG – MSG 2x12’ Upper body strength work	AM: LSG (11vs11) 3x13’ PM: Flywheel training – Injury prevention	MSG - SSG	LSG – MSG 2x12’	Friendly match	REST
Week 4	LSG – MSG 4x6’ Flywheel training – Injury prevention	Friendly match	MSG – SSG Flywheel training – Injury prevention Upper body strength work	MSG 4x 6’ (5vs5)	Friendly match	REST	REST
	SSG	LSG – MSG	MSG	LSG – MSG			

Week 5	(4vs4) / (3vs3) 2x6x1’/1’ Flywheel training – Injury prevention	Upper body strength work	4x 6’ (5vs5) + 3 Flywheel training – Injury prevention	Upper body strength work 2x12’	Friendly match	Friendly match	REST
Week 6	SSG (4vs4) / (3vs3) 2x6x1’/1’ Flywheel training – Injury prevention	LSG – MSG 2x12’ Upper body strength work	Friendly match	LSG – MSG Upper body strength work 2x12’	SSG (4vs4) / (3vs3) 2x6x1’/1’ Flywheel training – Injury prevention	Friendly match	REST
Week 7	Testing						

Statistical analysis

Statistical analyses were performed using SPSS statistics package version 25.0 (IBM, New York, NY, USA). Following the size of the sample, confirmation of data normality using Shapiro-Wilk test was performed. Levene's test for homogeneity of variances was employed to assess the equality of variances across groups or conditions. To assess the assumption of sphericity in repeated measures or within subjects, Mauchly’s sphericity test was employed. The effectiveness of each program (VI and CI) on the time was evaluated using a mixed model (time per group) ANOVA. A Bonferroni post hoc test for pairwise comparisons was conducted and the level of statistical significance was set at $p < 0.05$. Individual data analysis was presented using 2*SEM (standard error of the mean) to establish individual changes between responders and non responders athletes. To assess the magnitude of the changes, Cohen’s d effect size (ES) calculation was performed, with interpretations as trivial (< 0.2), small (0.2–0.5), moderate (0.5–0.8) and large (> 0.8) (24).

RESULTS

After confirm data normality, Levene’s test indicated homogeneity of variances ($p > 0.05$). To present the results more precisely according to the Mauchly’s test, Greenhouse-Geisser criterion was selected to control Type I error rates.

The group factors showed that there were no significant differences between groups in initial conditions, indicating two homogeneous groups in all measured variables after balanced assignment.

No significant differences were observed in the time x group interaction ($p > 0.05$). The Time factor reported that there were pre- to post-changes in performance variables (see Table 3). Positive improvement in performance variables is shown by the positive values of effect size. Both groups showed no changes in CMJ height, M505-ND or 30-m sprint time. Furthermore, both groups showed significant decreases in M505-D.

However, in the 10-m sprint, the CI group showed significant improvements (p = 0.04). There were also significant improvements in the 1RM values for both groups (p < 0.01).

Finally, for the flywheel performance variables, both groups showed increases in PP_{con} (VI: 9.42%; CI: 10.50%) and PP_{ecc} (VI: 13.80%; CI: 15.60%). Due to small sample size, to confirm the results, individual target has been contrasted with an individual analysis using 2xSEM (see Figure 2).

Table 3. Changes in performance after the variable intensity (VI) and constant intensity (CI) programs. CMJ: countermovement jump; M505-D: modified 505-Dominant side; M505-ND: modified 505 non-dominant side; 1RM: one-repetition maximum; PP_{con}: concentric peak power; PP_{ecc}: eccentric peak power; EO: eccentric overload; %: percentage change; ES: effect size; CI: confidence interval; *: $p < 0.05$.

	VI Group (*n* = 8)					**CI Group (*n* = 9)**				
Variable	**Pretest**	**Posttest**	**ES**	**CI**	**%**	**Pretest**	**Posttest**	**ES**	**CI**	**%**
CMJ (cm)	39.39 ± 4.29	37.94 ± 5.28	-0.30	(-0.58, -0,02)	-3.68	42.20 ± 5.30	41.57 ± 4.90	-0.11	(-0.33, 0.11)	-1.49
M505-D (s)	2.51 ± 0.06	2.61 ± 0.13*	-1.29	(0.07, 2.51)	3.98	2.49 ± 0.06	2.62 ± 0.09*	-1.83	(1.07, 2.60)	5.37
M505-ND (s)	2.58 ± 0.13	2.69 ± 0.23	-0.73	(-0.16, 1.62)	4.26	2.52 ± 0.06	2.62 ± 0.16	-1.32	(-0.42, 3.06)	3.79
SPRINT 10 m (s)	1.83 ± 0.09	1.80 ± 0.09	0.36	(-1.09, 0.36)	-2.06	1.81 ± 0.09	1.74 ± 0.07*	0.72	(-1.34, -0.11)	-4.02
SPRINT 30 m (s)	4.24 ± 0.17	4.30 ± 0.18	-0.31	(-0.09, 0.71)	1.41	4.16 ± 0.19	4.15 ± 0.16	0.05	(-0.38, 0.28)	-0.24
1RM (kg)	134.47 ± 20.84	141.12 ± 26.17*	0.28	(0.11, 0.46)	4.94	132.23 ± 20.41	140.68 ± 21.53*	0.37	(0.07, 0.68)	6.39
PP_{con} (W)	1488.21 ± 338.14	1628.54 ± 312.85	0.37	(-0.13, 0.87)	9.42	1635.11 ± 443.37	1808.24 ± 395.62	0.35	(0.08, 0.63)	10.50
PP_{ecc} (W)	1866.67 ± 531.74	2120.32 ± 573.33	0.42	(-0.08, 0.93)	13.58	1988.74 ± 448.68	2299.68 ± 465.61	0.63	(0.13, 1.12)	15.60
EO	25.18 ± 24.52	30.03 ± 19.13	0.18	(-0.43, 0.79)	19.26	29.68 ± 34.26	28.40 ± 15.42	-0.03	(-0.59, 0.53)	-4.31

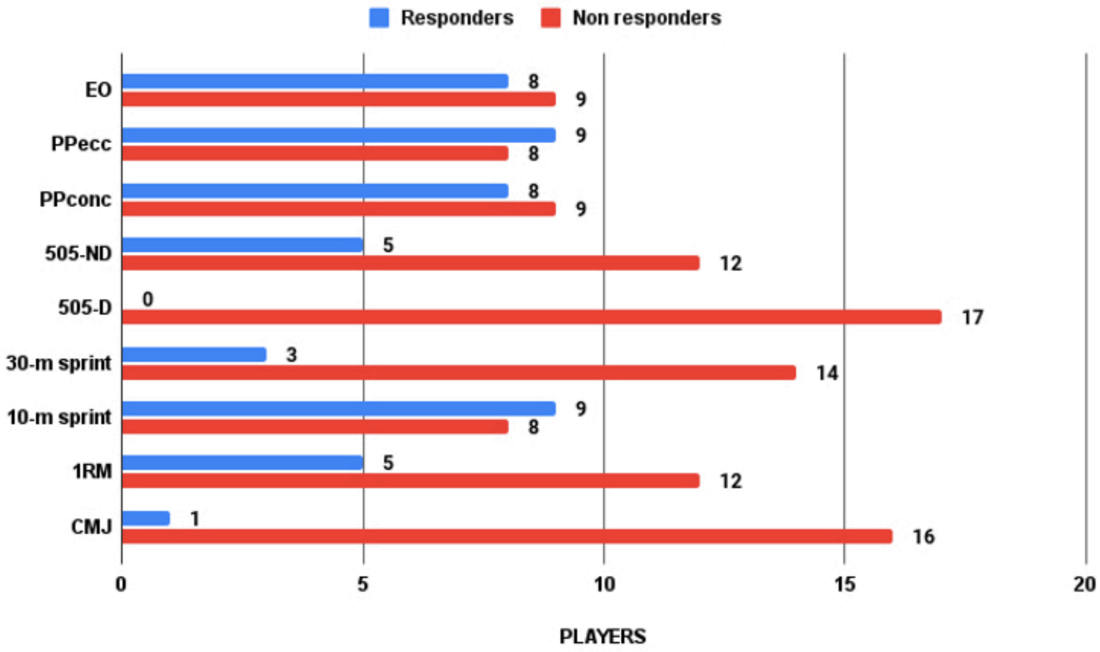

Figure 2. Individual results of different fitness testing. Athletes were divided into responders and non-responders based on 2xSEM criteria.

DISCUSSION

This study aimed to compare the effects of VI and CI FRT programs on soccer players' fitness performance. The main findings of this research are: the VI and CI groups have similar improvements in the 1RM variable; the CI group shows significant improvement for the 10-m sprint; and no difference was observed in the other variables apart from a significant decrease in M505-D.

Previous studies have reported the relationship of the 1RM squat with different performance tests in soccer (26, 27) and its influence on players' performance (29, 28). The benefits of FRT obtained in our study are similar to previous works (30, 20, 31). Thus, the inclusion of FRT can be an optimal way to improve maximal strength in lower limbs, optimizing sprint (32) and jump abilities (33), as a tool to improve match actions (28) or as an indicator of fatigue recovery after competition (29). The benefits mentioned for sprint performance have been observed in our results over short distances and are very important in soccer (34). Individual outcomes surpassing twice the value of SEM for the 10-m sprint test and flywheel squat power values indicate substantial performance changes according to the previous statistical analysis. These results agree with previous studies using FRT (35, 13, 36, 31, 10). Although the trend to improve the 10-m sprint test is observed in both groups, only the CI group obtained a significant difference after training. This finding could be due to the CI group using lower inertial loads. These results are relevant because sprint ability is one of the most important performance variables in soccer (37), being linked to soccer-specific tasks both in defensive and offensive actions (38, 39). According to Sabido et al. (18), lower inertial loads are a better option for eliciting high concentric peak power output values, and, according to our FRT results, a low load where high power is produced can be the best choice to optimize short-sprint ability. For this reason, the increases in PP_{con} and PP_{ecc} are greater in the CI group compared to the VI group (10.50% vs 9.42% and 15.60 vs 13.58 in PP_{con} and PP_{ecc} , respectively). Accordingly, recent research (40) shows that lower inertial loads can be optimal for trained subjects to obtain the maximal power values in the concentric and eccentric phases during squat exercises in FRT.

Studies on FRT have reported that this methodology can be very useful for improving jumping ability, COD and sprint tasks in soccer players (41, 13, 14). Nevertheless, our results show that the CMJ, COD and 30-m sprint did not improve in any of the groups after ten sessions of FRT, and even worse values were found for M505-D. These results are in line with individual analysis, showing a similar or high number of non-responders for several tests. Two reasons may explain the results obtained in our study. On the one hand, the absence of complementary training to improve jump ability has been proposed by Pecci et al. (19), who also did not find significant differences with female soccer players in CMJ height after six weeks of FRT. Thus, complementary tasks must be combined with FRT to obtain possible benefits in jump or COD abilities. On the other hand, the main hypothesis for these results is neuromuscular fatigue due to the high number of friendly matches (42). The purpose of investigating in an ecological context implied different changes in the FRT program and the impossibility of resting at 72 h from the last match to the final tests (32, 43).

To the authors' knowledge, this is the first study to compare the effects of two different FRT programs (VI and CI) on sports performance. Despite this, our study has some limitations. Firstly, the training volume and friendly matches calendar were very high, so it may not be possible to minimize post-match fatigue levels (44). Secondly, even though each player completed at least ninety percent of the sessions, the player role and external training load may be influencing the results. Thirdly, no control group was included because FRT was considered an important variable not only for optimizing strength in players but also for reducing the probability of injury. For this reason, and to have a greater number of players in each group, a control group was not considered in this study.

Finally, after training protocol no anthropometrical mesurements (i.e. body mass) were recorded. As previus research shown, the values of post-test can be conditioned by anthropometric changes (45, 46).

The findings of this study have a number of practical implications. Present findings suggest that VI and CI training improved strength levels. In addition, CI group showed significant improvements in the 10-m sprint. However, probably another type of training load (e.g. lower intensity and volume or complementary training) is needed to maximize performance in specific tasks such as the CMJ or COD test. Furthermore, it is necessary to control the fatigue levels and friendly matches calendar in pre-season periods in order to achieve functional overreaching. Thus, strength and conditioning coaches of soccer players with high 1RM/body mass ratio should to individualize FRT programs using CI (medium and lower inertias) and perform complementary training in promoting specific soccer performance improvements. Due to competitive density of most team-sports with short pre-season periods, this study concludes how to optimize performance outcomes using FRT in short periods of time (i.e., ten sessions during five weeks).

ACKNOWLEDGMENTS

The authors are grateful to all the participants in the present study. This research was made possible by financial support from Grant PID2019-109632R8-100. Pablo Asencio's contribution was supported by the Spanish Ministry of Science and Innovation (Grant no. PRE2020-091858). We would like to thank A. Oliver-López, M. López-Fernández and F. García-Aguilar for their help in testing sessions.

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AGRADECIMIENTOS

Imagen de fuente propia

Es sabido que los dispositivos flywheel devuelven la fuerza que se le aplica; a mí en estos simples párrafos no me llegan las palabras de agradecimiento para devolver a la gente de mi alrededor la fuerza que me han dado a lo largo de esta etapa.

Parece que fue ayer cuando ese chico subía con mamá a la terraza de casa mientras su padre estudiaba. Allí estaba ese banco y esas mancuernas viejas, que se sumaban a esas jornadas interminables de tenis que compartíamos en familia (*tata*, lo siento). Gracias a mi familia y a ese ambiente, empezó mi incesante curiosidad por el entrenamiento, y gracias a ella he realizado esta tesis doctoral. Gracias a mi hermana Rocío, que desde pequeña me has seguido en esta pasión y pese a ser la menor siempre me has dado grandes lecciones de empatía y madurez. Esos momentos y conversaciones que compartimos en tu habitación y siempre terminan entre risas con nuestros temas de siempre los llevo cada día conmigo (aunque últimamente me das mucha caña). Gracias a mi cuñado José Antonio por querer estar al día durante todo este proceso y esas infinitas conversaciones, donde como buen cuñado terminas siempre dándome la razón (no te queda otra). Gracias a mis padres, Enrique y Julia, por todo ese tiempo de calidad que nos habéis dedicado y que me llena de grandes aprendizajes. Esos aprendizajes tan poderosos, me han ayudado a poder afrontar muchos momentos con el coraje necesario a lo largo de esta tesis doctoral. Quiero destacar mi agradecimiento por inculcarme tantas cosas con vuestro ejemplo, no sólo en la formación del carácter, sino también muchas de ellas relacionadas con la actividad física, la salud y la cultura deportiva, que hoy son los pilares de mi vida y me han rodeado de experiencias y personas excepcionales. Gracias a ese hogar que habéis creado he podido llegar hasta aquí y me gustaría daros las gracias de todo corazón por la educación que nos habéis dado y por haber luchado siempre por lo que creéis mejor para nosotros.

Ha llovido mucho desde que preparé las pruebas de acceso al grado con mi amigo Fran Penalva, que fue una de las personas que me impulsó a tomar esa decisión. Desde el principio fui apoyado por mis amigos, los mismos que me han acompañado a lo largo de mis diferentes etapas. Ellos son mi pandilla *Dehoniana*, ese grupo de magníficas personas que tengo la suerte de conservar desde el patio del colegio. Gracias por todo vuestro ánimo durante el proceso y por aportarme muchas cosas que necesitaba aprender en mis inicios en la universidad (6). No me olvido de mi amiga *Albística* y de su capacidad para escuchar todos los “circos” desde tiempos inmemorables.

Mis primeros años en el grado fueron pasando y con ellos mis primeras tomas de contacto con la preparación física. En esos momentos conocí a Lucía, que pese a ser un novato en esto, decidió confiar en mí. Lo siento por aquellos entrenamientos, pero gracias a ellos surgió una gran amistad y nuevas preguntas (a veces demasiadas) que me han ayudado en todo este proceso. A partir de aquí, he ido trabajando en diferentes contextos y en cada uno de ellos he conocido a deportistas, alumnos, voluntarios para nuestras investigaciones y compañeros de profesión que me han aportado y a los que les agradezco mucho. Me gustaría hacer mención a todas las personas a las que he podido entrenar durante todos estos años tanto a nivel individual como en diferentes clubes y sus respectivos cuerpos técnicos, pero especialmente a todos los clientes de mi propio centro de entrenamiento. Gracias a vosotros cada día sigo cuestionándome mi trabajo mientras disfruto de toda esa calidad humana.

Gracias a vosotros he podido no solo hacer una parte de esta tesis sin financiación, sino además llenarla de recuerdos imborrables. Habéis sido un punto de inflexión. Como no, gracias a Sergio Sánchez (*Salvador*) por esas cenas, consejos y ayuda infinita con tu trabajo.

Por si no era suficiente, varios "metralletas" han amenizado mi camino, cada uno a su manera. Gracias a mis amigos Carreras, Pacheco, Iván y Carlos por todos los momentos compartidos, conversaciones, rutas, hamburguesas y todos esos planes únicos. Por sacarme constantemente de mi zona de confort y por contagiarme tanto de vuestra esencia. Además de ellos… el mundo del tenis nunca deja de sorprender, y me trajo a Izquierdo (*pétalo azul*) y Juanda (*venusiano*). Fue durante esos viajes en furgoneta, esos momentos de tensión en medio de la competición cuando entendí el significado del verbo reír. Gracias por esas sorpresas, por esas charlas serias pero llenas de risa a la vez (así somos) y por hacer de cualquier fisura una genialidad (incluyendo a la mítica *Juli de Lucena*).

Si el deporte y la amistad a veces van de la mano… el team "*Fair play*" debe ser nombrado… Gracias Isma y Mauro por seguir al pie del cañón desde el primer día. Por demostrar que el entrenamiento a veces tiene eso, deja huella y une a las personas. A nosotros nos unió y todo sigue igual pese a que hace ocho años que estamos separados y a veces por miles de kilómetros. Tengo mucho que agradecerle al entrenamiento y al deporte en general por haber podido construir un entorno rodeado de personas de este calibre y que me han acompañado durante este proceso. Gente que aparece sin ser llamada y decide quedarse. Como mi amigo "Ruli". Gracias por ser un compañero de vida, por las conversaciones y eternos debates que me regalas y nos hacen viajar sin movernos del nuestro sitio, para luego sacar conclusiones "marca de la casa" (…). Gracias por todo el apoyo que me has dado y por acompañarme a lo largo de este proceso (b. a.).

No sabía lo que me depararía este viaje predoctoral, mucho menos cuando conocí de primera mano Inglaterra y su gente. Y ello no hubiera sido posible sin la hospitalidad de Marco Beato. Gracias por acogerme en tu universidad, por tu hospitalidad, y por haber sido tan detallista conmigo. Por todas las enseñanzas que me ha dado Ipswich más allá de su fútbol y de las ciencias del deporte. Porque en ese tiempo hubo personas (Heather, Roland, Lindsay, María…) que me acogieron como familia sin conocerme y que han dado sentido a mi experiencia inglesa. Hablando de sorpresas, uno nunca puede imaginar conocer a personas que hacen que avanzar en línea recta sea más fácil como es el caso de Ana (*DdlL*). Gracias por tu trato conmigo, por tu espontaneidad, consejos y vitalidad que le has dado a este último tramo del camino. Higinio, gracias por esa visión que me has dado y por ofrecer siempre ánimo y soluciones ante cualquier contratiempo.

Todas estas etapas y vivencias han sido paralelas a mi trabajo en el Centro de Investigación del Deporte, un lugar conocido por su calidad profesional. Aunque desde dentro, he podido comprobar que lo que hace grande al centro es la calidad humana de sus integrantes. Siento que todos me habéis dejado grandes enseñanzas desde que fui alumno de grado, por eso pido disculpas por no poder nombraros a todos. En primer lugar quiero dar gracias a Dori, Juanpe, conserjes y todo el personal que nos hace la vida más fácil y están mano a mano con nosotros. La cúspide del centro está compuesta por personas que me han guiado más allá de lo académico. Manolo, gracias por todos los conocimientos que me has aportado, por todas esas conversaciones sobre preparación física que hemos tenido y por esas clases de planificación del entrenamiento donde te escuchaba ojiplático y no podía parar de preguntar. Eduardo, has hecho que me sienta como en casa desde el primer día que crucé estas puertas. Gracias por esas carreras, consejos y apariciones inesperadas en la sala siempre acompañado de tu pasión por entrenar. Gracias a Fran por esas conversaciones tan inspiradoras y por esa humildad que te caracteriza. Gracias Sarabia por tener respuestas, por esas herramientas de Excel que me ayudaste a crear y a las que le doy mucho valor, por esos momentos de docencia y todo lo demás que hemos compartido (*Batman*). Gracias Tomás, Casto, Isa, Amaya por esos almuerzos, viaje a la nieve (*circadianos*) y esos bailes donde hacemos honor al concepto "stiffness". Vicente y David, gracias por vuestro apoyo sobre todo en el ecuador del proceso. Pero si el sentido del humor es un pararrayos natural, no me puedo olvidar del *despacho de la risa*. Java, Peña, Manu gracias por vuestra meticulosidad y vuestros consejos, por el tiempo que me habéis dedicado y por la infinidad de bromas que hemos compartido estos años (siempre con elegancia).

Dentro del centro, otra parte de mis agradecimientos va dirigida a sus grandes dinamizadores: mis compañeros/as del programa. Quién me iba a decir que durante este proceso me acompañaría el gran Arturo Ballester (*Juan*) cuando le conocí en las pistas de tenis hace más de quince años. No hay rima para darte las gracias por tantas cosas en nuestras diferentes etapas. Gracias Casanova, Javi, Aarón por esas charlas sobre proyectos y metodología, y por no matarme en más de una ocasión. No me olvido de esas subidas a revolucionar la sala de becarios y de esos planes tan bien maquinados en los que siempre hay comida de por medio con Noemí, Kiket, Ana, Ilbar, Sabina, etc. y… de *Rober* y su "flama".

En el fondo del pasillo de la derecha del centro, está el Laboratorio de Aprendizaje y Control Motor, donde me he formado estos años. Francis, muchas gracias por dejarme ser parte de este grupo. Por abrirme las puertas y dejarme ser partícipe de los proyectos que se han desarollado en este tiempo y me han mantenido siempre fuera de la zona de confort. Por esas respuestas tan sabias y esa forma de mostrar el camino tan particular. Por tu ayuda con la gestión y tu elegancia con la codirección de esta tesis. Gracias Carla por tu trato conmigo desde el principio y por ser una auténtica *McGonagall*. A Alba por esas conversaciones y risas (*canijillo*) después de sacarte de quicio. Gracias a David Barbado por tirarme siempre mis argumentos por tierra de esa forma que me ayuda tanto a crecer y a ser más crítico (y por dejar que me copie eso que tú sabes). El laboratorio no sería igual sin su guardameta Óscar, ese informático que llegó para ser el testigo del caos (*me va, me va, me va*). Gracias por todo lo que nos has aportado desde tu llegada. A los doctorandos del lab, ese grupo humano que te hace sentir en familia. Mati e Isa, gracias por enriquecer nuestro laboratorio y darnos esa visión para perseguir objetivos. Charlotte, muchas gracias por mostrar que siempre puedo contar contigo, por esos paseos con charlas interminables y esos planes inesperados que han dado vida a estos años. *Miguelín*, muchísimas gracias por esas llegadas estelares al lab que alegran a cualquiera, por conversaciones de lunes donde siempre vas por delante, por esa docencia que hemos compartido y por mil cosas más (de los congresos mejor no digo nada). *Ferni*, muchísimas gracias por estar siempre para ayudarme, por tus detalles, por las conversaciones incómodas que hemos tenido y que han dado como fruto esta amistad (croché madrileño). Álex, (MSM) más allá de lo profesional y de nuestra forma de entender el entrenamiento, mil gracias por tantos y tantas anécdotas que hemos cultivado estos años y en distintos países (petardos, masaje, plátano, patín). *Carlitos*, llegamos al lab a la par. Desde el primer día tirando uno del otro con este proyecto y siempre aprendiendo de ti (*tattoomex*). Mil gracias por ayudar en todo, por ser ejemplo, por tu profesionalidad en todas las áreas a las que te dedicas y por todo lo que me transmites. Por último, hay dos personas que conozco desde hace mucho tiempo y que me han dejado una gran influencia más allá de lo científico. Xoxe y Adri (*tarjetas*), gracias porque siempre habéis sido pacientes y sinceros conmigo. Porque me habéis ayudado a evitar posibles errores y a subsanar los nuevos. Porque más allá de lo académico me habéis dejado enseñanzas que llevaré conmigo para siempre (como la de los paquetes).

Me gustaría finalizar este apartado dedicando unas palabras a mi maestro Rafael. Es difícil elegir las palabras de agradecimiento hacia una persona que ha sido la piedra angular de mi formación durante tanto tiempo y a la que considero mucho más que un director de tesis. Desde que empezamos en este camino siempre has sido sincero y objetivo conmigo en cada una de nuestras conversaciones en las barras (o comiendo ingentes cantidades de pan). Pese a eso, siempre has sabido mantenerme con los pies en el suelo, la cabeza en el cielo y la ilusión intacta por trabajar cada día. Me has individualizado el entrenamiento predoctoral acorde a mi naturaleza de ser un multitarea (lo siento, *míster*), y has hecho que siempre me sienta en la coherencia de practicar lo que enseño e intentar ir más allá. Al margen de lo académico, me has mostrado valores, experiencias, y personas en el camino que junto con esa genialidad han hecho que ser alumno tuyo sea toda una experiencia de vida. Gracias por enseñarme a escuchar para entender, por el valor de la paciencia infinita, y por todas esas cosas que explican el por qué a lo largo de todas mis etapas formativas solo he tenido un tutor.