

Effects of lower extremity isoinertial strength training on shooting speed, dynamic balance, and dribbling skills in adolescent football players

KAYA O¹, TUTAR M^{2*}, CAGLAYAN A³, KORKMAZ H⁴

¹ Rumeli University, Master's Degree of Sport Sciences, TURKEY

^{2,3} Gedik University, Department of Exercise and Sport Sciences, TURKEY

⁴ Gedik University, Department of Coaching Education, TURKEY

Published online: January 31, 2025

Accepted for publication: January 15, 2025

DOI:10.7752/jpes.2025.01024

Abstract:

Purpose. Research indicates that the quadriceps muscle group significantly influences jumping, balance, and ball-striking speed, while the hamstrings play a crucial role in maintaining knee stability during running and twisting movements. This study aims to evaluate the impact of isoinertial strength training, which is believed to enhance hamstring strength in young football players, on dynamic balance, dribbling skills, and shooting speed.

Materials and Methods. Forty-two U-16 football players from amateur team academies participated in the study and were divided into an experimental group (EG, n = 21) and a control group (CG, n = 21). In this study, young football players in the EG engaged in a 15-min isoinertial strength training program, incorporated into their warm-up routine twice a week for 8 weeks, before standard football training sessions. In contrast, the CG adhered to their usual warm-up and football training practices during the study period. The research design involved pre-test assessments, a 6-week isoinertial training intervention, and post-test evaluations. Pre-test data were collected from all participants before the training period, and post-test data were collected upon completion of the program. Various performance measures were evaluated, including height, body weight, body mass index (BMI), the Y-balance test for dynamic balance, dribbling skills, and shooting speed. These assessments provided a thorough analysis of both physical and skill-related factors pertinent to football performance. The CG maintained their standard training regimen without the addition of isoinertial strength exercises, facilitating a comparison of the effects of the isoinertial training intervention on the selected outcomes. **Results.** The data presented in this study indicate the potential of eccentric training to significantly enhance shooting speed ($p < 0.001$), balance ($p < 0.001$), and skill performance ($p < 0.004$) in adolescent athletes ($p < 0.001$). **Conclusions.** Improving skill-related performance during adolescence is crucial for creating effective movement patterns early in athletic development, thereby preparing athletes for more complex movements in the future.

Keywords: Soccer, ability, adolescent, isoinertial strength, y-balance

Introduction

Football is a sport affected by various factors, particularly those related to unilateral balance. Good balance is a key indicator of high performance in football. Lower extremity muscle strength is especially crucial for specific movements such as sprinting, jumping, changing direction, passing, and shooting. A decrease in muscle strength can result in decreased sports performance and increase the risk of muscle injuries. Numerous studies have demonstrated that muscle strength or imbalance can increase the risk of ankle and knee injuries (Seyhan et al., 2021). Additionally, hamstring strength is an important consideration in sports that involve high-speed running (Seymore et al., 2017).

Because football is a sport that requires both endurance and strength, players must possess high muscle strength. Research on muscular activation in football has shown that the muscle groups surrounding the knee joint exhibit high activation levels during activities such as kicking, jumping, running, and changing direction. Specifically, the quadriceps muscle group has been found to considerably impact essential football actions, including jumping, maintaining balance, and enhancing ball striking speed. Meanwhile, the hamstrings are vital for ensuring knee stability during running and directional changes (Cerrah & Yüksel, 2015). Both the quadriceps and hamstrings play crucial roles in stabilizing the knee joint during dynamic movements on the field. The hamstring muscle group is particularly crucial for activities such as passing, shooting, and changing direction, where athletes often need to balance on one leg (Wing et al., 2020). These muscle groups not only facilitate functional movement but also enhance overall efficiency and help prevent injuries during high-intensity, football-specific actions. When performing a gait or athletic activity, these two opposing muscle groups work in harmony to ensure coordinated lower limb movement (Kaeding & Borchers, 2014).

Muscle strength and balance are essential elements of various motor performances; thus, a certain degree of strength and balance is necessary to execute motor skills effectively (Hermassi et al., 2019). Traditional strength training, commonly used in football, incorporates different levels of functionality, including

resistance machines, free weights, and functional loading on cable machines (Signorile et al., 2017). Numerous studies have demonstrated that traditional resistance training enhances jump performance (Teo et al., 2016) and improves change of direction and sprint performance (Comfort et al., 2018). The load derived from the potential energy generated by the displacement of weights in traditional strength training dictates the training load. In contrast, isoinertial exercises use the load produced by the moment created from wheel rotation (Madruga-Parera et al., 2022). During isoinertial exercises, the force exerted by the muscles during the eccentric contraction phase is converted into elastic potential energy. The large force released during the stretch-shortening cycle enhances strength development (Karsten et al., 2016; Loturco et al., 2016). Football, a sport that requires both endurance and strength, requires that players maintain high levels of muscle strength. In studies examining muscle activation in football, it has been found that the muscle groups involved in moving the knee joint showed substantial activation during essential actions such as jumping, running, and changing direction. These frequently performed movements impose substantial strain on the lower limb muscles, especially the quadriceps and hamstrings. This underscores the critical role of strength in these muscle groups for both optimal performance and injury prevention. Such findings highlight the need for specialized strength training programs aimed at improving muscle activation and endurance in football players, particularly the dynamic movements required during games. Research has shown that the quadriceps muscle group considerably influences jumping, balance, and kicking speed (Cerrah & Yüksel, 2015). Therefore, it is crucial to investigate the impact of hamstring strength training on dynamic balance, dribbling skills, and shooting speed in football.

Furthermore, incorporating practical and low-cost isoinertial devices into training is recommended because they can enhance speed, jumping, direction changes, and shooting without reducing the amount of technical-tactical training (De Hoyo et al., 2015b; Maroto-Izquierdo et al., 2017a; Fiorilli et al., 2020). However, there is currently limited information in the literature regarding the effects of isoinertial strength training on shooting speed, dribbling skills, and balance.

The quadriceps muscle group has been shown to considerably influence jumping, balance, and kicking speed, while the hamstrings play a key role in maintaining knee stability during running and directional changes. Therefore, this study aims to examine the effects of isoinertial strength training, which is believed to enhance hamstring strength in football players, on dynamic balance, dribbling skills, and shooting speed.

Materials and methods

Participants

Forty-two football players from U-16 teams of amateur clubs participated in the study. The participants were randomly divided into two groups: the experimental group (EG, $n = 21$) and the control group (CG, $n = 21$). The average age of EG participants was 15.10 ± 0.53 years, with an average height of 150.2 ± 1.9 cm. Their mean body weight was 41.34 ± 7.9 kg, resulting in a body mass index (BMI) of 17.7 ± 2.9 . In the CG, the average age was 15.5 ± 6.6 years, and the average height was 155.3 ± 0.6 cm. Participants in the CG had a mean body weight of 46.1 ± 8.8 kg, with a BMI of 19.1 ± 2.8 . Before the study commenced, information about the participants' medical history, including any previous injuries, was collected. Participants with health issues such as soft tissue injuries in the musculoskeletal system (e.g., pain, swelling, or restricted movement in the upper or lower extremities), systemic diseases, neurological disorders, or upper and lower respiratory tract infections occurring in the month before the study were excluded. Additionally, individuals who chose not to participate were also excluded. Data collected from pre-tests and post-tests were recorded and analyzed statistically. In accordance with the Declaration of Helsinki, all participants were informed about the study's objectives, potential risks, and their right to withdraw at any time. Before participating, each individual signed an informed consent form. Ethical approval for the study was granted by the Rumeli University Ethics Committee (No. 2023/11-31).

Test protocol

The study was designed to include pre-tests, a 6-week isoinertial training program for the EG, and post-tests. Meanwhile, the athletes in the CG adhered to their traditional training regimen. The young football players in the EG engaged in a 15-min isoinertial strength training program integrated into their warm-up twice a week for 8 weeks, followed by regular football training. Conversely, the CG continued with their standard warm-up and football training programs. Initially, pre-test data were collected before the 6-week training period, followed by post-test data after the program, aiming to evaluate the impact of hamstring strength training on the EG. The EG involved measuring dynamic balance, dribbling skill, and shooting speed in adolescent football players. Anthropologic measurements such as height, body weight, and BMI were also recorded to assess the impact of hamstring strength training. The effectiveness of the 6-week isoinertial training program on participants was evaluated through performance tests. Specifically, the dynamic balance was measured using the Y-balance test, dribbling skill using Fitlight, and shooting speed with radar applications.

Measurements

Body Weight and Height Measurements

The height of the participants was measured in meters using a wall-mounted stadiometer (Holtain, UK), accurate to 0.1 cm. Measurements were taken with participants standing barefoot in an anatomical posture: feet flat on the ground, heels together and in contact with the wall, knees straight, and body upright. The height was

recorded at the point where the top of the head touched the measuring device. Body weight was measured using a digital scale (Seca, Vogel & Halke, Hamburg) with an accuracy of 0.1 kg. Participants wore light sportswear (shorts and a T-shirt), remained barefoot, and maintained an anatomical posture during measurement. Both height and body weight were measured twice, with the average of the two measurements recorded as the descriptive statistical value.

Y Balance Test

This test aimed to assess postural management. A "Y"-shaped figure was marked on the ground using tape, with centimeter measurement marks along the tape to track the athlete's movement. During the balance test, participants were instructed to keep their hands on their hips and their heels on the floor while lightly touching the farthest point with the reaching foot's fingertip. Measurements were taken barefoot in three directions: the anterior (ANT) reach was recorded from the toe at the center of the participant's foot; posterolateral (PL) and posteromedial (PM) reaches were measured from the heel of the foot to the farthest point the participant could reach. The athletes performed the test a total of nine times, with three consecutive attempts in each direction. During the measurement, any transfer of body weight to the reaching foot, lifting the heel of the stance foot off the ground, or moving hands away from the hips were considered errors, prompting a repeat of the measurement after the athlete was verbally informed (Engquist et al., 2015). Each participant's leg length was measured in centimeters while in a supine position, bilaterally from the anterior superior iliac spine to the distal part of the medial malleolus, and recorded. All reaching distances were measured in centimeters, and once the data were collected, the scores were normalized for each direction using the formula: $\text{Best Reach Distance} / \text{Leg Length} \times 100 = \% \text{ Maximum Reach Distance}$. This normalization was performed to eliminate any advantage owing to leg length (Gribble & Hertel, 2004).

Dribbling Skill: Fitlight

The Fitlight visual stimulus test battery was used in the study. To establish appropriate times and distances, athletes were given the opportunity to practice before the test, with the goal of matching their average reaction time while dribbling the ball in sync with the stimulus timings. The setup included 8 visual stimuli arranged in a circle with a radius of 2.5 m. Athletes attempted to touch the illuminated visual stimuli for 3 s while dribbling. After the visual stimuli were turned off, a transition time of 3 s was set for athletes to return to the center before moving to the next stimulus. The visual stimuli were randomly presented 15 times, and the average reaction time, along with the number of stimuli that athletes successfully reached and touched with their feet, was recorded. To evaluate the average reaction time and dribbling skill, both pre-test and post-test measurements were taken by the same team under identical weather conditions, at the same location and ground, with consistent distances and time intervals.

Shooting Speed: Radar

In the study, a radar gun was used to measure the athletes' speed. The Bushnell Velocity Speed Gun (Overland Park, Kansas) was used for this purpose. The shooting speeds of the footballers participating in the study were recorded during the pre-tests, and the impact of the training on shooting speed was further assessed in the post-tests.

Statistical analysis

Basic central tendency and dispersion parameters (mean, standard deviation, mean difference, and 95% confidence interval difference) were calculated for each variable. The Kolmogorov–Smirnov test was applied to confirm normality ($p > 0.05$). Data analysis was performed using the independent t-test, with statistical significance set at $p < 0.01$. The SPSS 25 software package (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis of the data.

Results

In this study, the impact of eccentric exercises on shooting speed, dynamic balance, and dribbling skills—key elements of football performance—was investigated. The results indicated that the improvements observed in all parameters for the EG athletes were statistically significant compared to the CG athletes ($p < 0.05$).

Table 1. Descriptive statistics of participants

Variables	EG	CG
Number (n)	$n = 21$	$n = 21$
Age (year)	15.1 ± 0.5	15.5 ± 0.6
Height (cm)	150.2 ± 1.9	155.3 ± 0.6
Weight (kg)	41.3 ± 7.9	46.1 ± 8.8
BMI (kg/m^2)	17.7 ± 2.9	19.1 ± 2.8

Values are expressed as means $\pm$ standard deviations. FG = foam roller group, SG = static stretching group, BMI = body mass index

Table 2. Changes in participants' variables before and after the tests

Variables	EG (n = 21)		T	p-Value	CG (n = 21)		T	p-Value
	Pre	Post			Pre	Post		
Y balance right	56.5±8.49	58.7±8.14	-8.307	.000*	58.6±4.75	59.3±4.82	-4.864	.000*
Y balance left	65.2±10.3	67.6±9.86	-9.772	.000*	66.7±4.76	67.6±4.61	-5.386	.000*
Dribbling	1.84±0.10	1.77±0.10	3.240	.004*	1.86±0.74	1.84±0.89	1.098	.285
Radar	72.5 ±7.63	80.3 ±6.68	-6.463	.000*	70.5 ± 11.4	71.9 ± 10.2	-2.397	.026

Values are expressed as means ± standard deviations. EG = experimental group; CG = control group

Table 2 presents the statistics for pre-test and post-test comparisons between the EG and the CG. In the EG, significant differences were observed in the Y-balance ($p < 0.001$) and Radar ($p < 0.001$) parameters. Moreover, a significant improvement was observed in the Fitlight parameter ($p < 0.05$).

Variables	Groups		T	p-Value
	EG (n = 21)	CG (n = 21)		
Y balance right (%)	20.5 ± 4.29	19.8 ± 2.86	4.471	0.000*
Y balance left (%)	27.3 ± 6.94	25 ± 5.32	4.582	0.000*
Dribbling	51.1 ± 4.4	86.1 ± 5.76	1.664	0.104
Radar	82.3 ± 7.30	88.3 ± 6.43	4.077	0.000*

Values are expressed as means ± standard deviations. EG = experimental group; CG = control group

Table 3 presents the statistical analysis of developmental differences between the EG and the CG. Significant differences were observed in the intra-group development comparisons for the Y-balance ($p < 0.001$) and Radar ($p < 0.001$) parameters.

Discussion

This study examined the effects of eccentric exercises on essential football performance parameters, including shooting speed, dynamic balance, and dribbling skills. The data analysis revealed significant differences in the EG for the Y-balance right ($p = 0.000$), Y-balance left ($p = 0.000$), dribbling ($p = 0.004$), and Radar ($p = 0.000$) parameters ($p < 0.001$). The CG also showed significant differences for the Y-balance right and Y-balance left parameters ($p < 0.001$). Intergroup comparisons indicated statistically significant differences in the Y-balance right ($p = 0.000$), Y-balance left ($p = 0.000$), and Radar ($p = 0.000$) parameters ($p < 0.001$). These findings indicate that eccentric exercises significantly improve dynamic balance and other important performance metrics in football. Analyzing the results of our study reveals that the improvements in shooting speed and dribbling skills, including agility, among the young footballers in the EG align with existing literature. Research has shown that training protocols that emphasize the eccentric phase of movement lead to greater strength gains compared to those with consistent loads during both concentric and eccentric phases.

It has been shown that isoinertial training leads to greater increases in strength and power compared to traditional training (Prieto et al., 2016) and should be integrated into training programs (Suarez et al., 2018). Research on the effects of isoinertial training shows significant improvements in all strength parameters, as reported by Petre et al. (2018), while Kale et al. (2019) highlighted strong gains in explosive power. Thus, shooting speed, a key variable in this study, is influenced by both leg muscle strength and the technical execution of the shooting motion. In this context, the quadriceps muscle plays a vital role in activities such as sprinting, jumping, and kicking, which are essential for football performance. Radman et al. (2016) performed a study with 66 amateur and semi-professional football players, measuring an average shooting speed of 24.8 ± 2.1 m/s. Likewise, Giombini et al. (2020) implemented an isoinertial training program consisting of two sessions per week over six weeks with 34 young footballers. The results showed significant improvements in shooting accuracy, further demonstrating the effectiveness of isoinertial training in enhancing football-specific performance. These findings indicate that isoinertial training can effectively enhance key performance metrics in football, such as shooting speed and accuracy, owing to its influence on strength and explosive power. Korkmaz's study reported that the isoinertial training group achieved a shot accuracy of 2.48 ± 0.46 , a shot speed of 24.79 ± 1.49 , and a shot quality of 3.66 ± 0.69 . In contrast, the training group recorded a shot accuracy of 2.31 ± 0.38 , a shot speed of 25.49 ± 2.00 , and a shot quality of 3.54 ± 0.59 (Korkmaz & Camlıgüney, 2022). In our study, a comparison of the pre- and post-test development in shooting speed revealed a statistically significant improvement among the athletes in the EG compared to those in the CG ($p < 0.05$). This improvement may be attributed to the development of the quadriceps and hamstring muscle groups resulting from isoinertial training.

Football is a sport that requires both endurance and strength, thus demanding players to have high muscle strength. Previous research by Rubley et al. (2011) examined the effects of plyometric training on shooting distance and found a significant increase in shooting distance for the EG compared to the CG after 14 weeks of training. Similarly, Sedano et al. (2011) reported a significant increase in shooting speed after 12 weeks of training. Moreover, research indicates that young footballers with superior jumping ability tend to strike the ball with more force. It is also well-established that the energy required for eccentric actions is approximately one-fifth of that needed for concentric actions in the same cycle (Tesch et al., 2017).

Many studies indicate that training protocols that overload the eccentric phase of movement lead to greater increases in force compared to those with constant loads in both eccentric and concentric phases (Lundberg et al., 2019). Several publications that support our study also report that prolonged eccentric exposure is effective not only in preventing injuries but also in improving sports performance. Additionally, eccentric training improves the storage and utilization of elastic energy, which increases concentric strength and speed (Martinez et al., 2017). Furthermore, numerous studies have highlighted that muscle strength or strength imbalances can increase the risk of ankle and knee injuries (Martinez et al., 2017). Hamstring strength has been identified as an important factor in preventing strain-type injuries in the hamstring muscle group during sports that involve high-speed running (Seymore et al., 2017). As previously mentioned, numerous studies analyzing the effectiveness of eccentric training have reported its benefits for injury prevention, which are linked to increased muscle strength, endurance, and power production at various joint angles (Lundberg et al., 2019). In our study, we measured reaction time as one of the parameters related to dribbling skill; this is defined as the interval from the moment a signal is given until a conscious action is initiated. It is defined as the process of transmitting stimuli from the muscle to the central nervous system via afferent nerves and then back to the muscles through efferent nerves. This process involves decision-making, leading the muscles to perform actions in accordance with the relevant signals (Dalkiran & Aslan, 2016). Eccentric muscle contractions require different activation strategies and programming processes in the central nervous system than those used for concentric contractions (Guilhem et al., 2010). At the muscle level, achieving similar force improvements during eccentric contractions requires significantly lower electromyographic activity compared to concentric contractions. This indicates that fewer motor units are needed to generate the same level of tension during eccentric contractions compared to concentric contractions, which leads to increased mechanical stress per motor unit. As the variation in stress per activated motor unit increases during extension work, controlling and coordinating eccentric muscle activities can become more challenging (Vogt & Hoppeler, 2014). Research has demonstrated a connection between enhanced agility performance and increased eccentric knee flexor strength (Chaabene et al., 2018; Morin et al., 2015). Therefore, it is highly advisable to include eccentric hamstring exercises in training programs for adolescents to improve athletic performance, particularly in sports that require explosive movements, such as football (Chaabene et al., 2017). In this context, it was determined that the eccentric exercises performed in our study had a positive impact on the agility, coordination, and reaction times of adolescent football players. Based on the pre- and post-test data, athletes in the EG who participated in isoinertial exercises completed the skill track—designed to test dribbling skills with a reaction device—in significantly shorter periods of time than the CG athletes who continued with traditional training, demonstrating a statistically significant improvement ($p < 0.05$).

Eccentric power is crucial in sports that require rapid changes in direction, where athletes must decelerate and stabilize their bodies quickly before re-accelerating in a new direction. Because the phases of a football game involve three-dimensional acts of both deceleration and acceleration with changes in direction (Fiorilli et al., 2020), using a cone-shaped device along with transfer rollers can offer additional advantages by facilitating multi-directional movements across various planes (Merino et al., 2021; Norrbrand et al., 2010).

There is a considerable improvement in direction change velocity after eccentric overload training (Liu et al., 2020). A similar effect is observed in the eccentric phases of isoinertial training owing to overload (Beato et al., 2020). During isoinertial training, sudden deceleration and pushing movements are effective in developing the skills necessary for changing direction (Maroto et al., 2017; De Hoyo et al., 2015). If deceleration time can be reduced and the sensation of deceleration enhanced during isoinertial exercises, which should include at least two training sessions per week, it is expected to positively impact direction change performance (Akyüz & Tutar, 2024). In two different studies involving 6- and 11-week isoinertial training for elite academy footballers, significant improvements in direction change performance were observed (Tous et al., 2016). Additionally, Fang reported increased change of direction speed in young football players after isoinertial training performed twice a week for 6 weeks in 2020 (Fang et al., 2020). It can be concluded that the drills performed with isoinertial devices during the training program for the EG effectively influenced the results and positively impacted the coordination and skills of young athletes. It is well-established that human balance ability comprises both static and dynamic aspects (Nikoforov et al., 2020), with balance being a crucial component in developing sports skills (Rudarli et al., 2024; Romahadi et al., 2020). Research investigating the relationship between force production and dynamic balance has largely focused on the concentric (Muehlbauer et al., 2013) and isometric aspects, often concluding that force and dynamic balance are independent of one another. However, more recent studies indicate that eccentric force, particularly in the lower limbs, may have a more significant impact on dynamic balance. For instance, Norris and Trudelle-Jackson (2011) observed high activation levels of the vastus medialis

during the lowering phase of the Star Balance Test (SBT), which may be attributed to eccentric contractions that absorb and stabilize forces acting on the body's center of mass (Kolias et al., 2022). Furthermore, Lockie et al. (2013) found that male team sport athletes who exhibited better stability on their left leg during the stance phase of the SBT also had stronger left knee extensors. This underscores the critical role of lower limb strength and stability in achieving enhanced dynamic balance (Hrysomallis, 2011; Chew et al., 2012). Isoinertial exercises have been shown to enhance static balance across diverse populations, while strength training, which includes both mobilization and explosive movements, has been found to improve both dynamic and static balance (Tous et al., 2016). Dynamic balance is affected by various factors such as range of motion, strength, proprioception, and gender, making it a crucial skill for football players. A well-developed dynamic balance enables players to maintain their center of mass during movement, thereby enhancing their performance. Notably, high levels of dynamic balance have been observed in professional and semi-professional football players, emphasizing its importance for athletic success (Gonzalez et al., 2002). Furthermore, research by Bryson et al. (2010) demonstrates that male football players experience substantial activation in their leg muscles during the stance phase. This emphasizes the importance of targeted strength training to improve balance during dynamic movements. Such training is crucial for optimizing performance and reducing the risk of injury during high-demand activities in football. The findings from the y-balance dynamic balance test, performed as part of pre- and post-assessments to evaluate changes in dynamic balance, revealed that the adolescent football players in the EG exhibited statistically significant improvements compared to their counterparts in the CG, who continued with traditional training programs ($p < 0.05$).

In summary, the relationship between lower limb strength, dynamic balance, and football performance highlights the importance of focused strength and stability training. This type of training can enhance balance control, thereby improving the execution of essential football skills such as shooting, passing, and changing direction.

Conclusions

Extensive research on the applications of eccentric resistance training has shown that these programs typically yield positive adaptations in both sedentary individuals and athletes (Franchi & Maffiuletti, 2019). As demonstrated in this study, the beneficial effects on the development of fast-twitch muscle fibers in young football players align with existing literature indicating that, at the molecular level, eccentric exercises can regulate satellite cell activity and transcriptional pathways in fast-twitch muscle fibers, which experience the most damage during contractions (Cermak et al., 2013).

The findings from our study, along with existing literature, suggest that muscle protein accumulation and increased cross-sectional area of muscle fibers during eccentric training may lead to potential long-term hypertrophic effects. This training method is likely to produce greater force output compared to both isometric and concentric contractions, offering enhanced work efficiency while consuming less energy. This ergonomic approach will support the execution of key skills that directly influence competition scores and performance, such as agility, dynamic balance, and shooting, which we examined within the context of a 90-min football match. Eccentric training's ability to support specific neural patterns—such as requiring fewer motor units to generate the same force during submaximal exercise when compared to other training methods—may enhance performance, particularly in young athletes, while also being more effective in injury prevention. It is essential to incorporate isoinertial devices that facilitate longer-duration eccentric muscle contractions more frequently in sports training or integrate them into training programs. This is important because repeated eccentric actions can lead to structural damage at the muscle level, where overstretched sarcomeres along the muscle fibers become progressively weaker and degrade, resulting in increased series cohesion. The primary mechanism behind improved muscle mechanical output and enhanced kinetic efficiency of the musculotendinous unit supports the effective use of isoinertial training for optimizing both acute and chronic adaptations. Eccentric exercises targeting the hamstring muscle group, which is often overlooked, especially in football, can reduce the risk of injuries by achieving a 3/2 quadriceps/hamstring ratio. Furthermore, these exercises can increase strength and power, leading to beneficial neuromuscular, morphological, and functional adaptations that enhance performance in key athletic tasks such as vertical jumps, sprints, and directional changes, which are crucial elements in football.

In future research, it is important to plan long-term studies involving a larger sample of athletes from various sports. Investigating changes in power and strength output of both upper and lower extremities, as well as the hamstring to quadriceps (H/Q) ratio and injury frequency among athletes, is recommended. Additionally, there is a need for studies focused on the effects of eccentric training in sedentary individuals, especially in the elderly population.

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgements

The authors would like to thank Falcon Scientific Editing for proofreading the English language in this paper.

References:

- Akyüz, M.S, Tutar, M, "Passing, Ball Control of Footballers in Our Country, Investigation of Dribbling and Shooting Skills" *Optimal Zenith Spor Bilimleri Dergisi*, 1(1), May 2024: 47-53. [Turkish]
- Beato, M., McErlain-Naylor, S. A, Halperin, I., & Iacono, A. D. (2020b). Current evidence and practical applications of flywheel eccentric overload exercises as postactivation potentiation protocols: A brief review. *International journal of sports physiology and performance*, 15(2), 154-161.
- Booyesen MJ., Gradidge PJ., Watson E. The relationships of eccentric strength and power with dynamic balance in male footballers. *J Sports Sci.* 2015;33(20):2157-65. doi:10.1080/02640414.2015.1064152.
- Bryson J., Burke Y., Chang JM., DeFrantz A., Easton J., Evans P., et al. Soccer Coaching Manual. Los Angeles: LA84 Foundation; 2012.
- Cerrah AO & Yüksel Y. Investigation of The Relationship Between Leg Mass Values And Some Fitness And Technical Parameters İn Adolescent Football Players. *Istanbul Üniversitesi Spor Bilimleri Dergisi.* 2015;5(2):20-9. [Turkish]
- Chaabene H., Prieske O., Negra YF., Granacher U. Change of direction speed: Toward a strength training approach with accentuated eccentric muscle actions. *Sports Med.* 2018;48(8):1773-9. doi:10.1007/s40279-018-0907-3.
- Chaabene H. Change of direction tasks: Does the eccentric muscle contraction really matter. *Sci Pages Sports Med.* 2017;1(1):1-2. doi:10.1007/s00421-010-1575-7.
- Cermak, N. M., Snijders, T., McKay, B. R., Parise, G., Verdijk, L. B., Tarnopolsky, M. A., et al. (2013). Eccentric exercise increases satellite cell content in type II muscle fibers. *Med. Sci. Sports Exerc.* 45, 230–237. doi: 10.1249/MSS.0b013e318272cf47
- Chew-Bullock TS., Anderson DI., Hamel KA., Gorelick ML., Wallace SA., Sidaway B. Kicking performance in relation to balance ability over the support leg. *Hum Mov Sci.* 2012;31(6):1615-22. doi:10.1016/j.humov.2012.07.001.
- Chiu LZ & Salem GJ. Comparison of joint kinetics during free weight and flywheel resistance exercise. *J Strength Cond Res.* 2006;555-56.
- Comfort, P., Dos' Santos, T., Thomas, C., McMahon, J. J., & Suchomel, T. J. (2018). An investigation into the effects of excluding the catch phase of the power clean on force- time characteristics during isometric and dynamic tasks: An intervention study. *The Journal of Strength & Conditioning Research*, 32(8), 2116-2129.
- Dalkıran O & Aslan CS. Investigation of The Reasons For Motivation of University Athletes To Sports. *Mehmet Akif Ersoy Univ Sos Bilim Enst Derg.* 2016;8(17):424-32. doi:10.20875/sb.33305. [Turkish]
- De Hoyo, M, Pozzo, M, Sañudo, B, Carrasco, L, Gonzalo-Skok, O, Domínguez-Cobo, S, Morán-Camacho, E. (2015a). Effects of a 10-week in-season eccentric-overload training program on muscle-injury prevention and performance in junior elite soccer players. *International journal of sports physiology and performance*, 10(1), 46-52.
- Engquist KD, Smith CA, Chimera NJ, Warren M. Performance comparison of student-athletes and general college students on the functional movement screen and the Y balance test. *J Strength Cond Res.* 2015;29(8):2296-303. <https://doi.org/10.1519/JSC.0000000000000906>
- Fang, G., Zhang, T., Zhong, S., Chen, X., Zhong, Z., & Wang, C. C. (2020). Reinforced FDM: Multi-axis filament alignment with controlled anisotropic strength. *ACM Transactions on Graphics (TOG)*, 39(6), 1-15.
- Fiorilli G, Mariano I, Iuliano E, Giombini A, Ciccarelli A, Buonsenso A, Di Cagno A. Isoinertial eccentric-overload training in young soccer players: effects on strength, sprint, change of direction, agility and soccer shooting precision. *J Sports Sci Med.* 2020;19(1):213-24.
- Franchi, M. V., and Maffiuletti, N. A. (2019). Distinct modalities of eccentric exercise: different recipes, not the same dish. *J. Appl. Physiol.* 127, 881–883. doi: 10.1152/jappphysiol.00093.2019
- Giombini, A, Fiorilli, G, Mariano, I, Iuliano, E, Giombini, A, Ciccarelli, A, Buonsenso, A, Di Cagno, A. (2020). Isoinertial eccentric-overload training in young soccer players: Effects on strength, sprint, change of direction, agility and soccer shooting precision. *Journal of sports science & medicine*, 19(1), 213.
- González-Fernández FT, Martínez-Aranda LM, Falces-Prieto, M, Nobari, H, Clemente, FM. (2022). Exploring the Y-Balance-Test scores and inter-limb asymmetry in soccer players: differences between competitive level and field positions. *BMC Sports Science, Medicine and Rehabilitation*, 14(1), 45.
- Gribble PA, Hertel J. Effect of lower-extremity muscle fatigue on postural control. *Arch Phys Med Rehabil.* 2004;85(4):589-92. <https://doi.org/10.1016/j.apmr.2003.06.031>
- Guilhem G, Cornu C, Guevel A. Neuromuscular and muscle-tendon system adaptations to isotonic and isokinetic eccentric exercise. *Ann Phys Rehabil Med.* 2010;53:319-41. doi:10.1016/j.rehab.2010.04.003.
- Hermassi, S., Schwesig, R., Aloui, G., Shephard, R. J., & Chelly, M. S. (2019). Effects of short-term in-season weightlifting training on the muscle strength, peak power, sprint performance, and ball-throwing velocity of male handball players. *The Journal of Strength & Conditioning Research*, 33(12), 3309-3321.
- Hrysomallis C. Balance ability and athletic performance. *Sports Med.* 2011;41(3):221-32. doi:10.2165/11538560-000000000-00000.

- Kaeding CC, Borchers J. Hamstring and quadriceps injuries in athletes. *New York: Springer*; 2014.
- Kale M, Ozmusul A, Heper E. Acute effects of isoinertial resistance application on sprint, vertical and horizontal jump performance. *Pedagogics Psychol Med Biol Probl Phys Train Sports*. 2019;2:76-82.
- Kolias P, Stavropoulos N, Papadopoulou A, Kostakidis T. Evaluating basketball player's rotation line-ups performance via statistical markov chain modelling. *Int J Sports Sci Coach*. 2022;17(1):178-88. doi:10.1177/17479541211009083.
- Korkmaz, H. Çamlıgüney, A.F. (2022). The Effect of Isoinertial Training on Jumping Performance on Young Football Players. *Uluslararası Spor, Egzersiz ve Antrenman bilimi Dergisi-USEABD*, 8(4), 94-102. DOI: 10.18826/useeabd.1141536
- Liu, R, Liu, J, Clarke, C. V, An, R. (2020). Effect of eccentric overload training on change of direction speed performance: A systematic review and meta-analysis. *Journal of Sports Sciences*, 38(22), 2579-2587.
- Lockie RG, Schultz AB, Callaghan SJ, Jeffriess MD. The effects of isokinetic knee extensor and flexor strength on dynamic stability as measured by functional reaching. *Isokinet Exerc Sci*. 2013;21(4):301-9. doi:10.3233/IES-130501.
- Lundberg, T. R., García-Gutiérrez, M. T., Mandić, M., Lilja, M., & Fernandez-Gonzalo, R. (2019). Regional and muscle-specific adaptations in knee extensor hypertrophy using flywheel versus conventional weight-stack resistance exercise. *Applied Physiology, Nutrition, and Metabolism*, 44(8), 827-833.
- Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. *Human Kinetics*; 2004.
- Madrugá-Parera, M., Bishop, C., Fort-Vanmeerhaeghe, A., Beato, M., Gonzalo-Skok, O., & Romero-Rodríguez, D. (2022). Effects of 8 weeks of isoinertial vs. cable- resistance training on motor skills performance and interlimb asymmetries. *Journal of Strength and Conditioning Research*, 36(5), 1200-1208.
- Maroto-Izquierdo, S, García-López, D, Fernandez-Gonzalo, R, Moreira, O. C, GonzálezGallego, J, De Paz, J. A. (2017). Skeletal muscle functional and structural adaptations after eccentric overload flywheel resistance training: a systematic review and meta-analysis. *Journal of science and medicine in sport*, 20(10), 943-951
- Martinez-Aranda LM, Fernandez-Gonzalo R. Effects of inertial setting on power, force, work, and eccentric overload during flywheel resistance exercise in women and men. *J Strength Cond Res*. 2017;31(6):1653-61. <https://doi.org/10.1519/JSC.0000000000001635>
- Merino-Muñoz, P., Vidal-Maturana, F., Aedo-Muñoz, E., Villaseca-Vicuña, R., & Pérez-Contreras, J. (2021). Relationship between vertical jump, linear sprint and change of direction in Chilean female soccer players. *Journal of Physical Education and Sport*, 21(5), 2737-2744.
- Meylan, C, Cronin, J, Nosaka, K. (2008). Isoinertial assessment of eccentric muscular strength. *Strength & Conditioning Journal*, 30(2), 56-64.
- Morin JB, Gimenez P, Edouard P, et al. Sprint acceleration mechanics: The major role of hamstrings in horizontal force production. *Front Physiol*. 2015;6:404. doi:10.3389/fphys.2015.00404.
- Muehlbauer T, Gollhofer A, Granacher U. Association of balance, strength, and power measures in young adults. *J Strength Cond Res*. 2013;27(2):582-89. doi:10.1519/JSC.0b013e31825c2bab.
- Nikiforov A, Rekovet A, Galerkin Y, Petukhov E, Rekstin A, Semenovskiy V, et al. Theory and practice of neural networks application to building mathematical model of centrifugal compressor vane diffusers. *IOP Conf Ser Mater Sci Eng*. 2021;1180(1):012025. doi:10.1088/1757-899X/1180/1/012025.
- Norrbrand L, Pozzo M, Tesch PA. Flywheel resistance training calls for eccentric muscle activation than weight training. *Eur J Appl Physiol*. 2010;110(5):997-1005. doi:10.1007/s00421-010-1575-7.
- Norris B, Trudelle-Jackson E. Hip- and thigh-muscle activation during the star excursion balance test. *J Sport Rehabil*. 2011;20(4):428-41. doi:10.1123/jsr.20.4.428.
- Petré H, Wernstål F, Mattsson CM. Effects of flywheel training on strength-related variables: A meta-analysis. *Sports Med Open*. 2018;4(1):55. <https://doi.org/10.1186/s40798-018-0169-5>
- Prieto-Mondragón LDP, Camargo-Rojas DA, Quiceno CA. Isoinertial technology for rehabilitation and prevention of muscle injuries of soccer players: literature review. *Rev Fac Med*. 2016;64(3):543-50.
- Radman, I, Wessner, B, Bachl, N, Ruzic, L, Hackl, M, Prpic, T, Markovic, G. (2016). The acute effects of graded physiological strain on soccer kicking performance: a randomized, controlled cross-over study. *European journal of applied physiology*, 116, 373-382.
- Romahadi D, Anggara F, Sudarma AF, Xiong H. The implementation of artificial neural networks in designing intelligent diagnosis systems for centrifugal machines using vibration signal. *Sinergi*. 2020;25(1):87-100. doi:10.22441/sinergi.2021.1.012.
- Rubley MD, Haase AC, Holcomb WR, Girouard TJ, Tandy RD. The effect of plyometric training on power and kicking distance in female adolescent soccer players. *J Strength Cond Res*. 2011;25(1):129-34. <https://doi.org/10.1519/JSC.0b013e3181b94a3d>
- Rudarlı, G., Tutar, M., & Kayıtken, B. (2024). Effects of Different Endurance Training Models on Players' Fitness Levels during the National Break in the Football Season. *Acta Kinesiologica*, 18(3), 69–77. Retrieved from https://akinesiologica.com/ojs_3.3.0-7/index.php/akinesiologica/article/view/279

- Sedano CS, Matheu A, Redondo JC, Cuadrado G. Effects of plyometric training on explosive strength, acceleration capacity and kicking speed in young elite soccer players. *J Strength Cond Res*. 2011;51(1):50-8.
- Seyhan R, Timurtas E, Polat M. Profesyonel futbolcularda alt ekstremite kas kuvveti asimetrisi, denge ve ayak bileği yaralanma riski arasındaki ilişkinin incelenmesi. *J Exerc Ther Rehabil*. 2021;8(2):178-86. <https://doi.org/10.15437/jetr.820854>
- Seymore KD, Domire ZJ, DeVita P, Rider PM, Kulas AS. The effect of Nordic hamstring strength training on muscle architecture, stiffness, and strength. *Eur J Appl Physiol*. 2017;117(5):943-53. <https://doi.org/10.1007/s00421-017-3583-3>
- Signorile, J. F., Rendos, N. K., Vargas, H. H. H., Alipio, T. C., Regis, R. C., Eltoukhy, M. M., ... & Romero, M. A. (2017). Differences in muscle activation and kinematics between cable-based and selectorized weight training. *The Journal of Strength & Conditioning Research*, 31(2), 313-322.
- Suarez-Arrones L, Saez de Villarreal E, Núñez FJ, Di Salvo V, Petri C, Buccolini A, Mendez-Villanueva A. In-season eccentric-overload training in elite soccer players: Effects on body composition, strength and sprint performance. *PLoS One*. 2018;13(10). <https://doi.org/10.1371/journal.pone.0205332>
- Teo, S. Y., Newton, M. J., Newton, R. U., Dempsey, A. R., & Fairchild, T. J. (2016). Comparing the effectiveness of a short-term vertical jump vs. weightlifting program on athletic power development. *Journal of strength and conditioning research*, 30(10), 2741-2748.
- Tesch PA, Fernandez-Gonzalo R, Lundberg TR. Clinical applications of iso-inertial, eccentric-overload (YoYo™) resistance exercise. *Front Physiol*. 2017;8:230519. <https://doi.org/10.3389/fphys.2017.00241>
- Tous-Fajardo, J, Gonzalo-Skok, O, Arjol-Serrano, J. L, Tesch, P. (2016). Enhancing change-of-direction speed in soccer players by functional inertial eccentric overload and vibration training. *International Journal of Sports Physiology & Performance*, 11(1).
- Vogt M, Hoppeler H. Eccentric exercise: mechanisms and effects when used as training regime or training adjunct. *J Appl Physiol*. 2014; doi:10.1152/japplphysiol.00146.2013.
- Wing, C. E., Turner, A. N., & Bishop, C. J. (2020). Importance of strength and power on key performance indicators in elite youth soccer. *The Journal of Strength & Conditioning Research*, 34(7), 2006-2014.