Gonzalo-Skok and Tous-Fajardo
Sports Medicine - Open (2026) 12:119
https://doi.org/10.1186/s40798-026-01093-y

Sports Medicine - Open

REVIEW ARTICLE

Open Access

Movement Configuration Elements in Football Players: Beyond Dynamic Correspondence Principles

Oliver Gonzalo-Skok[1*] and Julio Tous-Fajardo[2]

Abstract

In real-world football training, limited time is available for strength and conditioning sessions during the in-season period. The search for time-efficient strategies that concurrently enhance several locomotive-specific actions while preventing injuries seems crucial. Individual sports coaching literature has provided valuable concepts such as "transfer of training" and "dynamic correspondence" to describe the extent to which a given exercise may enhance sports performance, based on how closely it reproduces the exercise's mechanical, neural, and metabolic demands. However, given the highly dynamic and stochastic nature of football movements, there is a need to introduce a more comprehensive and advanced training paradigm that includes the so-called movement/action configuration elements. These variables aim to shape how game-based football actions evolve during a real match situation and include the need to efficiently anticipate/compensate for perturbations and unknown or unexpected events by alternating eccentric overload unilateral, variable, and multidirectional movements. A review of how these elements may shape football movements is conducted to ultimately provide practical recommendations and tools for daily practice.

Keywords High-intensity actions, Repeated high-intensity efforts, Uncertainty, Fluctuations, Unilateral, Decision-making

Introduction

In elite football, the aim of a strength training program should be to optimize how players move on the pitch and maintain high-intensity efforts throughout the match/season while reducing the injury rate (i.e., limiting layoff time from competition and practice). However, limited time is available for strength and conditioning during the in-season period, given to highly congested calendars [1], which consequently increases the injury rate [2]. This reality challenged us to seek more time-efficient training strategies to maintain or even create the adaptations needed to tailor those aims [3, 4].

Football players perform most of their specific actions in an unexpected (i.e., unpredictable), highly dynamic, and stochastic environment, which leads them to adopt anticipatory behaviors (feedforward mechanisms and co-contractions) [5] or to generate new movement strategies [3]. Specifically, most football actions are unilateral, variable, and multidirectional [6], such as kicking, passing, pressing, cutting, or jumping, and primarily involve one limb across the three spatial dimensions. Rather than repeating these moves cyclically, they alternate them without a predefined route or pacing strategy, resulting in an ad hoc duration. Several perturbations [7], unknown [8], or unexpected [5] events from opponents or teammates usually constrain their pre-planned movement

*Correspondence:
Oliver Gonzalo-Skok
oligons@hotmail.com
[1] Department of Communication and Education, Universidad Loyola Andalucía (Campus Sevilla), Avenida de Las Universidades S/N, 41704 Dos Hermanas, Seville, Spain
[2] FC Barcelona, Head of Physical Preparation, Barcelona, Spain

© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

strategies, leading to a sudden breaking action that produces high eccentric force [4], which is often required to reorganize the plan or to fake the defender. Consequently, there is a need to introduce more challenging training methods, including the above-mentioned variables, that enable players to perceive and respond to the environment, potentially inducing emergent behaviors to generate optimal movement synergies [9].

The current narrative review aims to analyze how certain configuration elements used during strength training sessions can help football players better respond to the ecological validity of football compared with a traditional approach. The following sections will address the previously considered aspects in detail, providing the reader with practical tools for daily practice. The movement configuration elements are shown in Fig. 1.

Methods

Literature Search

A structured literature search was undertaken in MEDLINE/PubMed, Scopus, Web of Science Core Collection, and SPORTDiscus from database inception to 31 March 2026. Reference lists of relevant articles, systematic reviews, and meta-analyses were also manually screened to identify additional publications relevant to the review's conceptual framework.

Search terms were combined using the Boolean operators AND and OR and were adapted to the syntax of each database. The search strategy combined terms related to the population, training modality, biomechanical or neuromuscular characteristics, and performance outcomes. The core search strategy was:

("team sport" OR soccer OR football OR basketball OR handball OR rugby OR athlete*) AND ("resistance training" OR "strength training" OR "eccentric overload" OR "eccentric training" OR "flywheel training" OR "isoinertial training" OR "inertial training" OR "unilateral training" OR "bilateral training" OR "plyometric training" OR "velocity-based training") AND ("neuromuscular performance" OR "change of direction" OR agility OR sprint* OR acceleration OR deceleration OR "repeated sprint ability" OR "repeated power ability" OR jump* OR power OR asymmetry* OR "inter-limb asymmetry" OR "injury prevention" OR "injury risk" OR "anterior cruciate ligament" OR ACL OR landing OR cutting OR "knee biomechanics" OR "neuromuscular control")*

Additional searches were conducted using terms specifically related to the review themes, including force vector, rotational training, three-dimensional movement, unilateral training, bilateral training, eccentric overload, flywheel training, velocity loss, repetitions in reserve, repeated power, unknown loads, feedback, unanticipated, unexpected, decision-making, stochastic training, variable practice, movement variability, and perturbation training.

Eligibility and Study Selection

Eligible studies included human athletes or physically active individuals, with priority given to team-sport populations such as football, basketball, handball, and rugby. Studies were considered if they examined strength-training interventions, movement-training strategies, neuromuscular or biomechanical

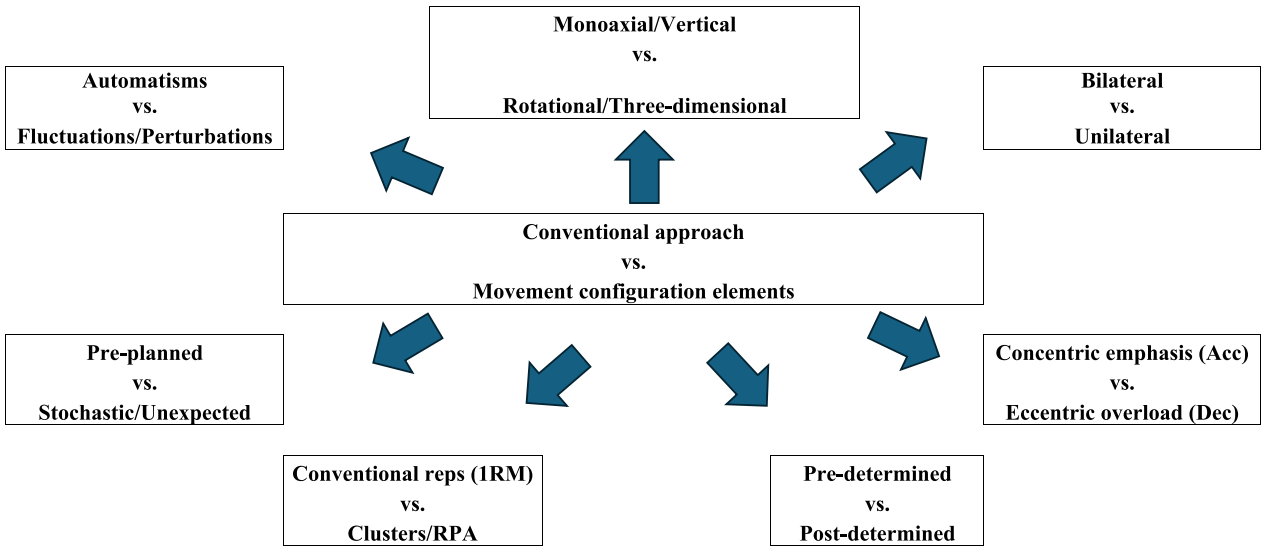


Fig. 1 Conventional approach vs. movement configuration elements

characteristics, or motor-learning processes related to the review framework.

Eligible outcomes included maximal strength, power, jump performance, sprint performance, acceleration and deceleration capacity, change-of-direction ability, repeated-sprint or repeated-power performance, inter-limb asymmetry, movement variability, neuromuscular control, lower-limb biomechanics, and injury-related outcomes. Experimental studies, observational studies, biomechanical investigations, systematic reviews, meta-analyses, and foundational mechanistic papers were considered. Review-level and mechanistic evidence were used to contextualize findings rather than to provide evidence equivalent to that of primary intervention studies.

Studies were excluded if they were conducted in non-human models, did not address the population, training approach, or outcomes relevant to the review framework, or were limited to conference abstracts, editorials, letters, or protocols without outcome data. Only full-text publications in English or Spanish were considered.

Narrative Synthesis

Following the removal of duplicate records, 94 unique references were retained for the final narrative synthesis. Evidence was synthesized qualitatively and interpreted in terms of its contribution to each of the seven proposed sections.

Movement Configuration Elements

Mono-axial vs. Three-Dimensional

Traditionally, team-sport players have performed vertical movements to improve specific abilities, a practice rooted in weightlifting, in which all movements involve lifting weights in the frontal plane. However, one of the main changes in specific game-action training is the involvement of multiple force vectors. While this theory has recently appeared in the strength and conditioning literature [6, 10–12], its application has several years of experience in the real-world context. One of the first studies to examine the main mechanical determinants of both acceleration and maximum speed in team-sport players was conducted by Martin Buchheit's research group [13]. Their findings suggested that training aimed at improving maximal speed may also enhance acceleration performance. In contrast, athletes seeking to maximize acceleration should place greater emphasis on developing the ability to apply force horizontally.

The importance of applying force in the desired direction to achieve optimal movement performance has been recognized as a key factor in improving sports performance [14]. Specifically in linear sprinting, it seems to have greater relevance the production of a higher ratio of the horizontal force component compared to total force production, that is, a more horizontal force resultant in every step, as well as the decline or inability to maintain this ratio. Indeed, elite sprinters can develop a greater horizontal force per body mass unit at any velocity than sub-elite sprinters [14]. Hence, the main question is how football players can apply more horizontal force and achieve a better orientation of the resultant force. A study has assessed the influence of force vectors on specific abilities, such as vertical jumping (vertical force vector) and linear sprinting (posteroanterior force vector), in a group of young athletes [10]. As such, the main aim was to compare the effects of performing the front squat (vertical) or hip thrust (horizontal) exercises for 6 weeks (biweekly, 4 sets×6–12 repetitions at one-repetition maximum [1RM]). As previously hypothesized, powerful hip extensors might result in a better orientation of the force resultant [14]; the current results confirmed this assumption. While the hip thrust group substantially improved the 20-m linear sprint (ES = 0.46), the front squat group achieved greater vertical jump performance (ES = 0.45). Therefore, this study supposedly supported the force-vector training theory for enhancing specific abilities in team-sport players [10].

However, the force-vector theory and the consideration of the hip-thrust as a "horizontal" exercise are argued to be based upon mechanical misconceptions since they give primacy to the direction of force relative to the global frame, whereas what is most important is the direction relative to the athlete, as is suggested by the principle of dynamic correspondence [15, 16]. Although training programs that include the hip thrust exercise have shown beneficial effects [11], other training modes appear more consistent with the principles of dynamic correspondence. Thus, a longitudinal study was developed that examined team sports complexity for the first time in an experimental setting [6]. In this regard, this study aimed to compare a traditional paradigm (6 sets of the squat exercise performed bilaterally in the vertical axis) with a novel paradigm (1 set of 6 movements executed unilaterally and multidirectionally) (Fig. 2), carried out in the flywheel conical pulley in both paradigms [6]. Similarly to Contrera's study [10], the main findings were that the traditional group exhibited more robust adaptations in actions in which force application was primarily vertical. In contrast, the multidirectional group reached greater improvements in actions requiring horizontal and lateral force application. Along the same lines, 24 young elite basketball players were assigned to a flywheel training program, which included variable unilateral horizontal or lateral movements for 6 weeks (1 set of 4 exercises) [12]. Interestingly, an adaptation period was included in both groups (who performed the same exercises for 8 weeks) before the training period, with no substantial

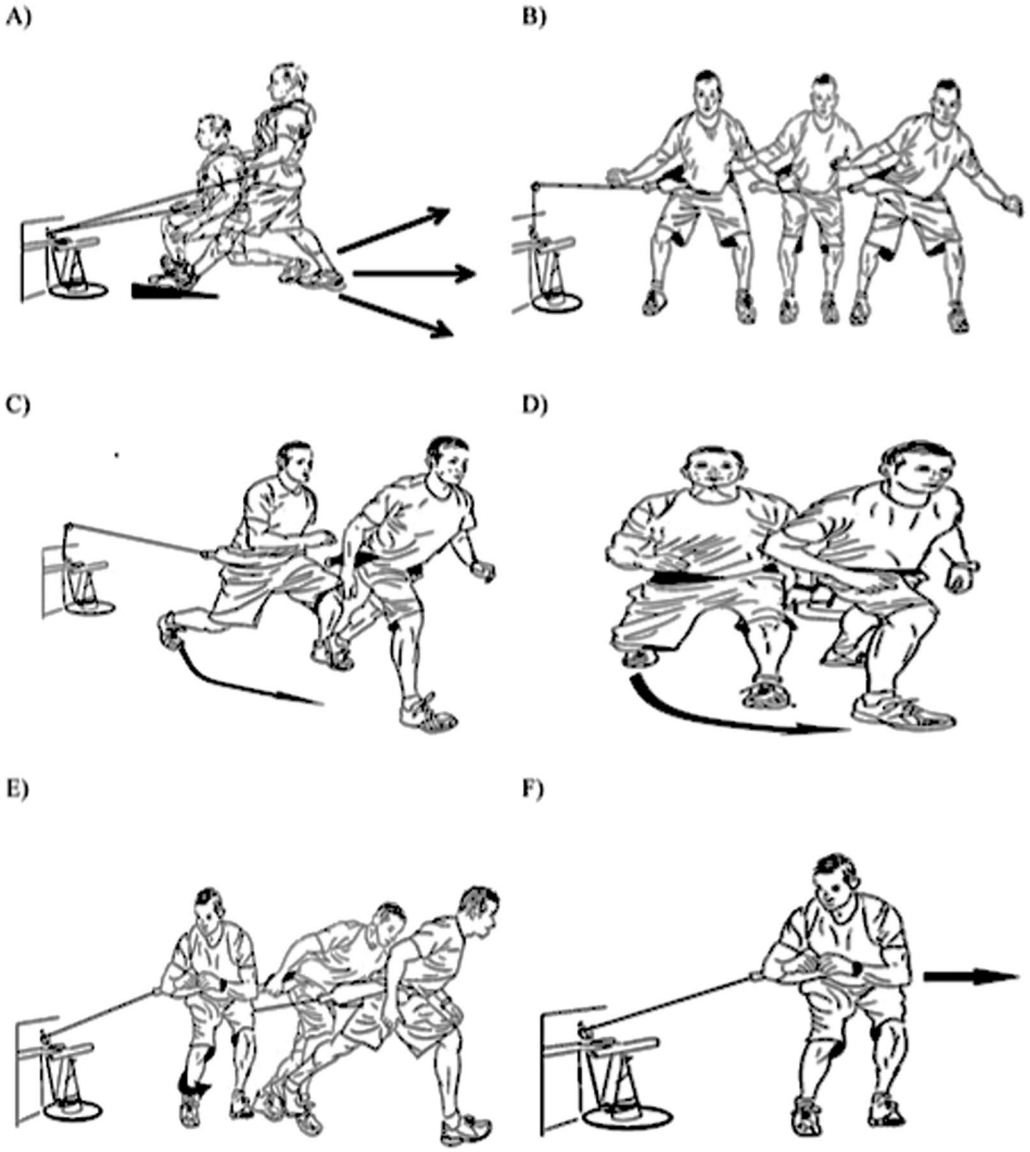


Fig. 2 Exercises performed during the variable unilateral horizontal/lateral training program and the corresponding force-vector): **A** lunges (anteroposterior/posteroanterior), **B** shuffling displacements (medial–lateral/latero-medial), **C** front side-step (posteroanterior/anteroposterior), **D** crossover step (rotational/anteroposterior), **E** lateral crossover step (rotational/latero-medial) and **F** lateral squat (medial–lateral/latero-medial). Adapted from Gonzalo-Skok et al., International Journal of Sports Phyisiology and Performance, 2017, with permission

differences except for lateral jumps, favoring the horizontal group. Even though both groups improved almost all performance tests, greater improvements in lateral (lateral jumps and lateral squat power) and horizontal (5-m and front-step power) movements were found in the specific force vector (medio-lateral/rotational or anteroposterior/posteroanterior, respectively). Therefore, it seems that the application of force vectors may play a key role in the specific adaptations.

On the other hand, if focus on the medial–lateral and rotational components of displacement, the proposed exercises should, globally, involve the external rotators, abductors, or gluteus medius [17]. In fact, unexpected events elicited greater torque in both external rotators and abductors, and, interestingly, the gluteus medius and gluteus maximus achieved significantly greater electromyographical (EMG) activity ($p < 0.05$) compared to the pre-planned condition. Team-sport players are continuously dealing with uncertain situations, and optimal activation of the gluteus maximus and medius will be key to hip control and reducing hip internal rotation, which leads to knee valgus, one of the

main injury mechanisms of the anterior cruciate ligament (ACL).

Another study [18] examined the possible relationship between hip adduction and hip external rotator strength and the unexpected one-legged change of direction (COD) kinetics and kinematics. Specifically, on a platform connected to an interface, a signal appeared on a screen just in front of them: red (single-leg landing), a right-pointing arrow (landing and side-step), or a forward arrow (landing and front side-step). All landings were registered through a 3D system and a force platform. The main conclusion was that players with greater external hip rotator strength showed better motor control (less hip internal rotation and knee valgus) during both unexpected landings and COD.

Lastly, a prospective study conducted with team-sport players aimed to determine whether isometric hip strength (external rotation and abduction) measured before the start of the competitive season could predict the degree of ACL injury likelihood [19]. Fifteen non-contact ACL injuries were registered during the competitive season. Baseline hip strength values of those players who had suffered an injury were significantly lower ($p = 0.003$ and $p < 0.001$) than those of non-injured players. Indeed, a greater probability of suffering an injury was defined as a cut-off point of < 20.3% or < 35.4% of body mass for hip external rotator and hip abductor strength, respectively.

Thus, it seems that the strength of the hip external rotators, abductors, gluteus medius, and gluteus maximus is of great importance for hip control and, consequently, could help minimize the risk of severe injury, such as ACL injury. Therefore, a lateral squat that requires great hip control improves the navicular drop and positively impacts multidirectional speed abilities (i.e., curvilinear and multiple COD tests) [20]. Consequently, these exercises could be incorporated in the medial–lateral area to improve the efficiency in the frontal plane. On the other hand, reverse wood chops would be an appropriate exercise to stimulate the hip external rotators through a global movement while rotating.

In summary, using a combination of movement planes and force vectors may properly develop the ability to perform multidirectional activities in team-sport athletes.

Bilateral vs. Unilateral

Traditionally, and based on the bodybuilders' array, strength training has been commonly executed bilaterally. One of the most important questions is whether the ecological validity of unilateral exercises for improving team-sport performance is real. A recent meta-analysis [21] assessed the effects of unilateral or bilateral plyometric training on jumping, sprinting, and COD in young team-sports athletes. Despite no clear between-group advantages, unilateral plyometric training appeared to provide greater benefits in single-leg tasks, such as jumping and COD. Previously, a similar meta-analysis conducted in healthy individuals [22] also showed a positive specific effect for the training modality. In this regard, it seems that specific training modalities should be tailored to the specific aims targeted during training.

Between-limbs strength difference is known as functional asymmetry, limb symmetry index, or between-limbs imbalance. It has been deemed a valid and useful tool for detecting functional deficits in players who have previously sustained an ACL injury [23]. In this regard, it is worth noting that only 30–50% of those players who suffered an ACL injury or reconstruction were considered symmetrical (an asymmetry lower than 10% in hop tests such as unilateral vertical, unilateral horizontal, double unilateral horizontal after a drop jump, unilateral lateral, and unilateral square tests). On the other hand, the remaining players (50–70%) were deemed to be at high injury risk, as they had a fourfold higher probability of sustaining another lower-body injury [23]. Furthermore, the return-to-play success after an ACL injury has been analyzed in a sample of 503 football players [24]. The conclusions were dramatic: players with a functional hop test asymmetry ≥ 15% had a relative risk of returning to play that was 2.5 times lower than those with normal values (i.e., < 15%). Therefore, it can be established that a hop test assessment in any return-to-play process may be one of the most successful indicators of return to sport.

The controversy over the influence of asymmetries on performance continues. As such, 132 young male football players (U-14 to U-18) of a Spanish professional club were analyzed (Gonzalo-Skok et al., 2018, unpublished results). The assessment was compounded by unilateral vertical and horizontal jumps; a 40-m linear sprint (10-m splits), with peak velocity defined as the best split time in the 40-m sprint; a 10-m sprint (5 + 5 m) with a 180° COD performed with both legs; and the V-cut test. These players were divided into symmetric and asymmetric based on vertical and horizontal jumping asymmetry. Compared with the above-mentioned studies, in which the sample was divided into two groups or pooled data were used to examine the influence of functional asymmetries on displacement, the division in the present study was based on Hopkins' approach (i.e., magnitude-based inferences) [25]. Accordingly, the aim was to have at least a small effect size (ES = 0.2) difference between symmetrical and asymmetrical players. Consequently, several players were excluded from the analysis because they were in the mean group values. It is worth noting that there were no substantial differences when vertical asymmetries were used to establish these groups. Nevertheless,

substantially greater performance was found in almost all displacement variables (linear sprinting and COD) when these groups were based on horizontal jumps. Therefore, an asymmetry in the application of horizontal force might negatively affect displacement performance.

In conclusion, it seems that players who exhibited functional asymmetry may have a greater probability of sustaining a lower-limb injury, a lower probability of returning to play successfully, and poorer performance in displacement activities. This fact underscores the importance of performing training workouts designed to minimize functional asymmetries in both the return-to-play process and training optimization.

Effects of Unilateral Training to Improve Functional Asymmetries

A case study assessed the horizontal force applied by each limb on a non-motorized treadmill, determining the weak and strong legs with respect to the horizontal force [26]. After a 6-week control period, a unilateral training program to strengthen the weak limb (hip extension exercises) was added to the bilateral training usually performed during the previous 6-week training program. The current results showed a substantial improvement in the weak leg's horizontal force, a reduction in horizontal force asymmetry, and improvements in both maximum velocity and power during sprinting. These results suggest that unilateral training might help decrease horizontal force asymmetry and, consequently, improve the linear displacement performance.

On the other hand, 22 young male basketball players were randomly assigned to either unilateral or bilateral combined strength training [27]. Each group performed $3 \times 90^{\circ}$-squat sets of a post-determined number of repetitions (stopping the set when power output dropped to < 10% of maximum power established at the beginning of each set), 2 sets of 4 drop jumps, and 2 sets of 4 countermovement jumps (CMJ) biweekly for 6 weeks. The only difference was that all exercises were performed unilaterally (starting with the weakest leg) or bilaterally. After the training program, the unilateral group substantially decreased the unilateral power asymmetry in the squat exercise and showed a substantially greater improvement than the bilateral group.

A recent meta-analysis [28] showed beneficial effects of unilateral plyometric training in reducing lower-limb asymmetries, whereas no reductions were observed with bilateral plyometric or complex training. Furthermore, a previous meta-analysis [29] again followed the principle of training modality or specificity, as unilateral resistance training showed better benefits for unilateral jumping. In contrast, bilateral training was better for bilateral strength performance. On the other hand, a previous meta-analysis [30] found no differences between the two modalities in horizontally oriented movements.

Therefore, unilateral training might help to improve the functional asymmetry. In addition, despite some controversy, training specificity may be the best option based on your performance aims (unilateral exercises for unilateral actions, while bilateral exercises for bilateral actions). Given the dynamic correspondence of current actions in team-sport players and the impact of such training on functional asymmetries, unilateral training should have a prominent role in training sessions aimed at performance optimization (improving performance and minimizing the risk of injury).

Concentric Emphasis (Acceleration) vs. Eccentric Overload (Deceleration)

With the advent of inertial resistance machines (e.g., YoYo™, Versapulley…), football players can achieve eccentric overload and even incorporate it into any analytical or specific movement. However, an eccentric overload is difficult to achieve. It has previously been described that a minimum level of experience is required to develop such eccentric overload [31]. Furthermore, many team-sport players struggle to decelerate in small spaces in real-world contexts. Given that maximum decelerations can be recorded throughout a game using tri-axial accelerometry, it has been determined that such decelerations are key in team-sport players. Specifically, it has been reported that there are more high-intensity decelerations (24 vs. 19 in the 1st and 2nd halves, respectively) than accelerations (14 vs. 12) in elite football [32]. In the same line, performing either maximum acceleration or deceleration had a negative impact on them (10.4% and 11.4%) at 5 min post-execution, though performance recovered 10 min after such maximum activity [33]. Interestingly, there was a moderate-to-large relationship between the total number of accelerations and decelerations and creatine kinase (CK) immediately post-match, at 40 h, and at 60 h post-match in English footballers [34]. Thus, being ready to perform these activities may help football players recover faster between games, minimizing fatigue.

On the other hand, it is well known that braking forces determine both COD performance and stability. Jindrich et al. [35] showed that such forces prevented the excess of rotation during CODs, while Spiteri et al. [36] reported that the fastest players were those who applied greater vertical braking forces in the last step during sprinting with CODs of 180°. Notwithstanding, the most interesting finding was that the most effective deceleration strategy consists of applying greater horizontal braking forces in the penultimate step rather than the last [37]. Given that braking sooner reduces the high horizontal torque,

a more efficient support should be predisposed, allowing for the application of a greater propulsive force.

Regarding injury prevention and performance, it is worth noting that those studies were published with Sevilla FC's young players [38–40]. Firstly, they observed substantial improvements in linear sprinting, jumping, and injury severity compared to a control group after a 10-week training period with 1–2 sessions per week, performing 3–6 sets of 6 repetitions in both YoYo Squat and Leg Curl exercises [39]. Furthermore, a similar training program was found to have beneficial effects on several kinematic variables during the execution of two COD tasks: side-step and crossover step [40]. Secondly, the acute effects of carrying out 4 sets of 6 repetitions (120 s of passive recovery) in the YoYo Squat were examined. Contrary to the common belief that relates this kind of workout to an acute fatigue on players' functional abilities, a substantial improvement was found in almost all tests administered (side-step and crossover step COD, vertical jumping, and 20-m linear sprint) compared to a conventional warm-up group (i.e., cycloergometer) [38]. Conversely, although significant neuromuscular impairments were observed immediately and 48 h post-training after similar training workouts to the above-mentioned ones [41], it should be taken into account that the lower players' competitive level and, above all, the lack of flywheel training background. Unless you have deep knowledge (i.e., individual analysis of fatigue and recovery) of your players, it is questionable to separate your training sessions by at least two days based on the data presented in one study, as it will mainly depend on the above-mentioned factors. Along the same lines, the effects of adding a weekly flywheel training session were analyzed using several functional performance tests in a group of elite handball players [42]. The flywheel training consisted of 4 sets of 8 repetitions for the bilateral half-squat and unilateral lunge exercises through flywheel devices during a 7-week training program. A substantial beneficial effect was found in the flywheel group compared to the control group (both groups continued their habitual strength training) for right and left triple-hop distance and power output during both the eccentric and concentric phases of the half-squat and lunge exercises. Additionally, including an eccentric overload session per week (five exercises: split squats, forward and backward lunges, squats, and hip extension) in youth football players showed marginal increases in total distance and high-speed distance during small-sided games (n = 1117 observations) [43]. Interestingly, some mechanical variables, such as accelerations and decelerations, decreased. It may be possible that more functional exercises transfer better to specific actions developed during small-sided games.

Lastly, several studies that have implemented a more functional approach, emphasizing movement variability and functional movements, in contrast to the traditional approach previously described, which is characterized by conventional exercises and repetitive sets using rotational inertial devices, are examined. Firstly, the effect of a combined training program that included exercises with the Versapulley, YoYo Squat, or superimposed vibrations (Fig. 3) on COD ability performance was examined [4]. The effects were clearly greater in such a group than in a group that performed sequential training consisting of resistance exercises, fence jumps, or jumps with headshots [44]. Furthermore, reactive power measured using a 5-s rebounding jump test showed substantial improvements in the combined eccentric functional group and a strong relationship with changes in COD. In another study [6], they compared the effects of performing 6 sets of the same exercise (bilateral vertical squat) with 6 different unilateral multidirectional exercises (1 set) performed with the conical pulley. The second group obtained more robust improvements across the pool of COD tests analyzed, particularly for the shorter distance (5 + 5 m) with the right leg. Although no significant between-group differences were found in the left leg, subsequent analyses revealed an increase of approximately 0.6 m relative to the squat group (enough distance in football to win a ball or to gain an advantage in basketball). This example demonstrates that a non-significant result might be a worthwhile change for a player, coach, and team.

Different meta-analyses have shown positive effects of flywheel training on variables related to sport performance in athletes and healthy populations [45] and, compared with traditional resistance training, in promoting muscle power in untrained and well-trained athletes [46]. Finally, a very recent study compared the effects of traditional strength training (i.e., 70–80% 1RM) with a unilateral flywheel training program through similar exercises (lateral squat, split squat, and forward lunge) during 8 weeks in football players [47]. The most interesting finding was that unilateral flywheel training effectively enhanced eccentric braking-related capacity and COD efficiency, with clear transfer to football-specific high-intensity match-play demands (i.e., high-intensity accelerations and decelerations).

Thus, those abilities that require muscle power, accelerating, decelerating, and changing direction seem to be beneficial using mainly functional exercises providing an eccentric overload, such as flywheel training, in comparison to traditional strength training.

Predetermined vs. Postdetermined

Morton's bifactorial theory [48] holds that a stimulus will provoke both positive and negative effects, and the

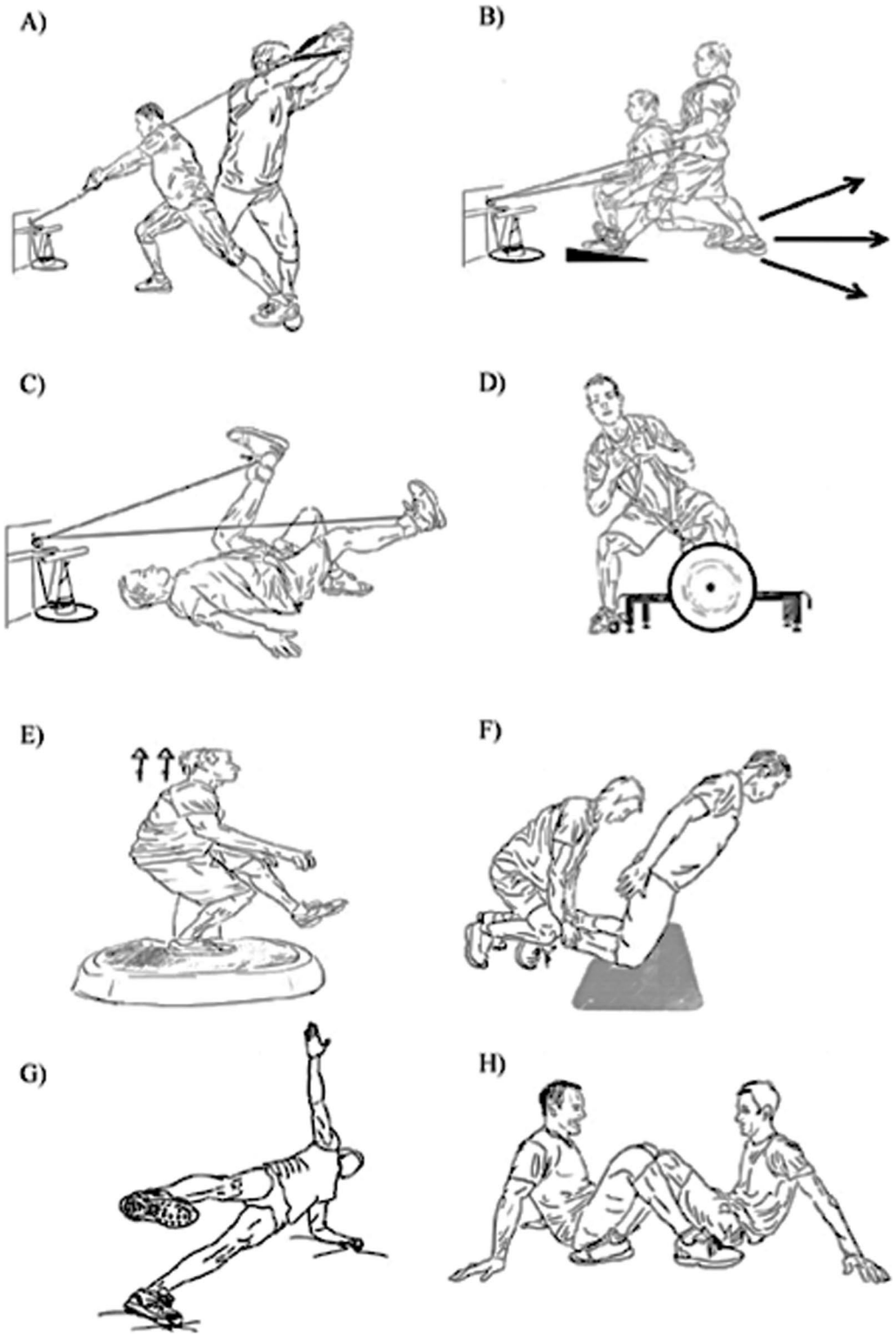


Fig. 3 Functional eccentric-overload and vibratory training program. **A** Diagonal trunk rotations (reverse wood chop), **B** backward lunges, **C** unilateral hamstrings kicks, **D** lateral squats, **E** vibration-platform unilateral squat, **F** Nordic-hamstring exercise, **G** rotational side-bridge, and **H** partner-resisted hip abductions and adductions. Reprinted from Tous-Fajardo et al., International Journal of Sports Physiology and Performance, 2016. National rights reserved by the authors/Human Kinetics

effect will determine the athlete's current state. Furthermore, there are strategies known as priming [49] (mid-term performance enhancement) and post-activation potentiation (acute, immediate effects) that acutely improve football performance. Such strategies can be developed through predetermined or post-determined protocols. Specifically, predetermined protocols involve a fixed number of repetitions, whereas post-determined protocols are adjusted according to performance in each repetition. Randell's doctoral thesis analyzed the effect of performing a predetermined number of repetitions, with or without feedback (i.e., to show how jumping height was immediately incorporated into the externally loaded jump exercise) [50]. After 6 weeks of training, the group that received feedback achieved considerably greater improvements in vertical and horizontal jumps, as well as in linear sprint performance. This study led us to understand that including information about what was happening in each repetition would improve repetition quality (increased speed and power) and, consequently, neuromuscular performance.

Despite a meta-analysis that found no evidence that feedback training (post-determined) was superior to traditional resistance training (predetermined) [51], a recent article emphasizes the potential of feedback to enhance neuromuscular performance, recovery, and sports performance [52]. Several studies have shown that training with an indefinite number of repetitions beforehand (post-determined), adapted to the subject's current situation, compared with training with a fixed number of repetitions, may yield greater neuromuscular improvements, facilitate accurate training load prescriptions, enhance motivation, and reduce unnecessary fatigue [52, 53]. This is due to the following:

a) Biofeedback allows training to be individualized and optimized [54].
b) Achieve more robust and resilient adaptations over time [55].
c) Avoid repetitions that negatively affect neuromuscular performance (empty training) [56].

Conventional Repetitions and Sets vs. Clusters/Repeated Power Ability

Over the last few years, a growing body of literature has focused on how repeated high-intensity efforts are a key performance factor in team sports. In this regard, Gunther Tidow [57] was among the first to show that traditional long sets included low-quality training (characterized by high power decrements and fatigue). For example, to perform 10 high-quality reps (maximum 10% power decrement), you will need a between-reps recovery of 9 s. In addition, a very interesting finding was that 5 high-quality reps could be repeated without a recovery period between them [57]. When improved either peak velocity or power in a specific movement, the aim will be to maintain those peaks over time with two different approaches:

– Power endurance
– Repeated power ability

Both concepts were proposed by Julio Tous-Fajardo & Gerard Moras in the late 90s. While power endurance involves maintaining several repetitions above a threshold (>90% of maximum power), repeated power ability (RPA) involves repeating high-intensity actions with incomplete recovery between sets [58]. Power endurance could allow us to maintain mean velocity during specific actions (defending, fast breaks, attack, and defensive transition in football) [58]. In contrast, RPA might help us to keep this velocity level from the 1st game action to the last minutes of the game [58]. Such ability has been considered a fundamental prerequisite in basketball [59]. Nevertheless, it has been reported that there are significantly fewer high-intensity actions in the final stages of a game [60–62]. Thus, it should be considered to include this kind of workout with two aims.

In a classic study on the electromechanical delay, it was observed that after performing a run at 70% of maximum oxygen consumption (VO_{2max}) with constant CODs (as commonly occurred in team sports), a significant increase in electromechanical delay was produced, leading to both muscle stiffness and force application decrease [63]. If football players add to this the fact that repeated exposure to constant CODs leads to a substantial decrease in hamstrings electromyographic activity [64], the scenario could involve a potential loss of knee stability and a possible higher risk of an ACL injury. From this point of view, where there is a greater risk of injury as high-intensity actions are repeated or fatigue accumulates, the main question is how football players can minimize that loss of performance.

Firstly, a study was proposed with professional rugby players in which the effect of performing a combined repeated power session (squat with the maximum power load with superimposed vibrations at 30 Hz) of 3 blocks of 6 sets × 6 reps with 20 s and 4 min of recovery between sets and blocks, respectively, and a repeated sprint session (similar volume carried out with sprints) was analyzed. The first training session of the week was a repeated power training session, while the second was a repeated sprint training session. It was compared with exclusively performing a repeated sprint workout (twice per week) [65]. Even though both training

groups improved, the combined training group was more effective in both relative and absolute power in the squat exercise and, even, in the best sprint time and the mean time in the repeated sprint ability (RSA) test. Subsequently, a study involving young basketball players compared a control group with an RPA group that performed 1–2 blocks of 5 sets of 5 repetitions at maximum power on the leg press exercise twice per week for 6 weeks [66]. The RPA group demonstrated improved performance in repeated high-intensity effort tests, including repeated-sprint ability (RSA) and repeated change-of-direction (RCOD) performance. However, while the improvement in the RSA test was mainly produced through an enhancement of the last sprint, the RCOD improvement was related to the best sprint. Lastly, an upper-body RPA training program was examined over 7 weeks [67]. The main finding was an improvement in intra-set power fluctuation in the last cluster. This phenomenon has previously been observed in high-level athletes (unpublished data). However, the novelty was to use intra-cluster power variability and to examine the relationships between the decrease in fluctuations and those changes in the RPA index or the mean power in the last cluster. These findings may indicate that a greater consistency during a cluster when you are fatigued facilitates power maintenance.

A study conducted by Arede et al. [68] in U-18 basketball players to examine the effects of performing an RPA protocol with randomized recovery times (in an attempt to simulate the iterative nature of team sports) on analytical (jumping, linear velocity, speed of change of direction) and game-specific (accelerations, decelerations) physical performance variables [68]. Recovery times between sets (5 sets of 5 repetitions) were randomized between 15 and 35 s, while the time between the 2 blocks performed twice a week for 10 weeks was stable (3 min). The most interesting findings were that the group that performed the RPA protocol obtained significant improvements in the number of high-intensity accelerations and decelerations per minute (ability to accelerate and decelerate over time) and in the peak of both acceleration and deceleration during the game.

Finally, the most recent published study compared the two approaches: power endurance vs. RPA [58]. Both training programs represented effective means of developing several adaptations, such as maximal dynamic strength, maximum power output, the ability to repeat power, and fatigue-resistance indices in the upper body. In the short term (4 weeks), the ability to repeat power appears to improve with both approaches. However, the mean power fluctuation may need longer training periods, with power endurance training apparently more effective [58].

Therefore, the conclusion of the entire analysis process may be that RPA training is effective in improving the repetition of high-intensity actions over time or in a match (a greater number of actions), as well as in maintaining performance levels (maintaining the frequency of actions for a longer time) and, consequently, minimizing the effects of fatigue that have a direct influence on the risk of injury, while a mixed strategy emerges to improve its efficacy/efficiency over different variables. It is worth noting that using longer recovery periods (i.e., 30 and 45 s) between clusters the first time you use this strategy will provide greater power output values than shorter periods (i.e., 15 s), as it has been described through flywheel training in the quarter squat and Romanian deadlift [69].

Preplanned vs. Stochastic/Unexpected

The first studies published by Besier [5] and Lloyd [70] were inspiring, as they introduced the unexpected concept of COD and, consequently, a greater threat to the knee joint. Later, similar results were found in other movements, such as stop-jump tasks [71], landings [72], or when fatigue was added [73]. Luckily, if you systematically introduce these unexpected events over time, players can decrease the joint's aggressiveness after either several years of practice [74] or a sensorimotor training period [75]. Such adaptations might be produced through the development of feedforward mechanisms. Such a mechanism is defined as the player's ability to adequately muscle pre-activation [76]. Hence, the variability of tasks will allow the proprioceptive–vestibular–visual system to interpret a situation that, though not identical to previously experienced ones, is presented during a game or training session, thereby reducing the time required to perceive the stimulus. Definitely, it considers those previous adjustments to any specific movement, such as supporting, landing, throwing, kicking, struggling, etc. Inadequate muscle pre-activation prior to these actions may increase the demands of movement execution and injury risk, as demonstrated by Zebis et al. [77, 78]. Notably, a relatively simple neuromuscular intervention incorporating unexpected stimuli and perturbation-based exercises improved anticipatory muscle activation patterns, evidenced by a reduced vastus lateralis-to-semitendinosus activation ratio.

On the other hand, in a very interesting study, coming from neuroscience [79], it has assessed the effect of three types of training had during a period of 2 weeks in a task that interrelated visual, auditory and motor aspects: auditory stimulus (2 possibilities) with a vocal response depending on the stimulus, visual stimulus (2 possibilities) with a motor response depending on the stimulus or a combination of the previous proposals. After the

training sessions involving decision-making tasks, varied stimuli, and different motor responses, information processing speed improved. Thus, the great practical application of the study and its integration into team sports is that the proposed tasks, which involve constant decision-making with several possibilities and modify movement patterns in both eccentric and concentric phases, will allow players to respond faster to the stimulus.

One of the main limitations to measuring the effect of introducing decision-making actions (i.e., unexpected events) during neuromuscular training is how to do it. In this regard, Martín et al. [80] developed a repeated-sprint ability test with a decision-making COD in each sprint. This test consisted of 6 × 20-m (10-m + 10-m) sprints separated by 20 s of active recovery while jogging back to the initial position (Fig. 4). Each sprint was compounded by a 10-m linear sprint plus a 10-m sprint with three potential directional options according to a traffic light fixed after the first 10-m linear sprint: (a) linear sprint, (b) a linear sprint after performing a 45° COD to the right, and (c) a linear sprint after executing a 45° COD to the left. It has been shown to be reliable, useful, and responsive for detecting training-induced changes, to distinguish between age categories, and to be valid (with significant correlations with match-related performance) in young football players [80].

Thereafter, a longitudinal study was carried out with 24 young football players (U-17) [81]. They performed four movements (lunge, defensive shuffling, side-step/crossover step, and lateral crossover step; 1 set per exercise) with the conical pulley. The main difference was that one group executed such exercises with three different constraints:

- Random: right/left lunge selection.
- Unanticipated: reacting to an external stimulus.
- Unexpected: responding to a perturbation.

The other group performed them without constraints for 8 weeks. After the training period, the constrained group achieved substantially greater improvements in mean time (6 sprints) on the RSA-RANDOM test than the non-constrained group [81].

Understanding that the unexpected and the unknown are, in a way, complementary, Hernández-Davo has developed an interesting thesis on the training effect of unknown loads [8, 82–84]. One of the most interesting findings was that ignorance of the load being moved elicits both a greater rate of force development and power than knowledge of the load during the first part of the concentric phase of a bench press. The electromyographic activity of the main muscles involved in bench press movement was similar in both situations (i.e., known and unknown). However, the main mobilizer (i.e., deltoid) was activated 50 ms before the start of the movement [84]. These small details can help us to understand how the inclusion of these elements (i.e., unexpected) in basic movements could configure several areas in the long term. Indeed, the group that trained with unknown loads substantially improved handball throwing velocity compared to the group that used the same load. However, the latter group knew the loads for 4 weeks [8].

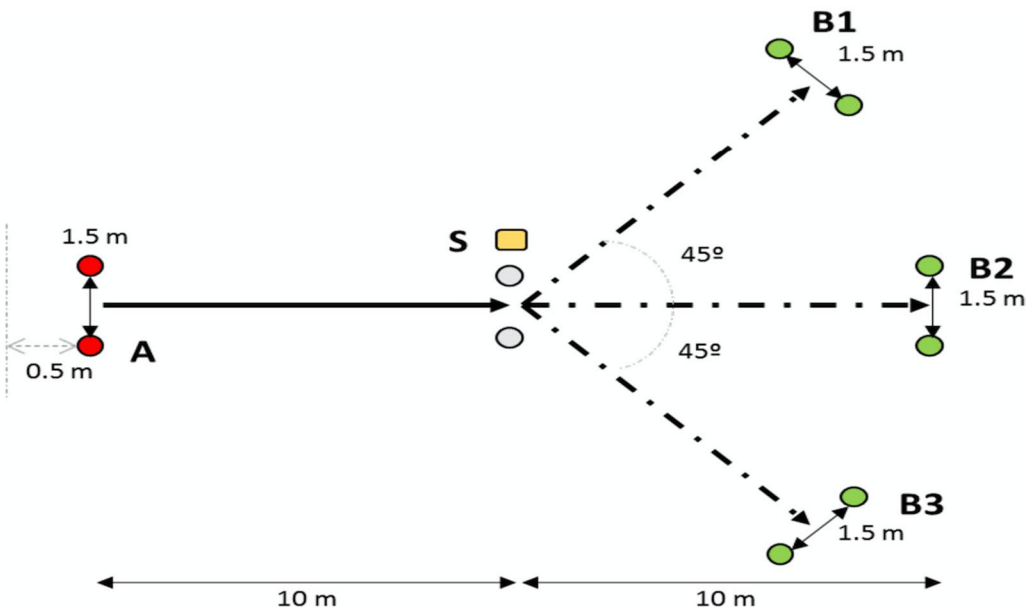


Fig. 4 Schematic illustration of the RSA random test. Adapted from Martín et al., (2018), with permission from Georg Thieme Verlag KG

These results support incorporating unexpected, unknown, and random events into neuromuscular training to improve both performance and injury prevention.

Automatisms vs. Fluctuations/Perturbations

Athletes have been considered to use a proactive motor control strategy dominated by feedforward/anticipation control in situations of disturbance or instability [85]. The usual choice to optimize performance under these conditions is to train on unstable surfaces. However, the major limitation of using these training elements is a reduction in force application by up to 60% [86]. Therefore, an important issue to consider is whether disturbances are required to induce fluctuations. As with many aspects of sports training, this relationship likely depends on the specific training context and intended adaptations. From an analytical perspective, training interventions may be designed to improve either movement speed or movement efficiency [3]. Although substantial evidence supports strategies to enhance specific movement actions, considerably less research has focused on improving movement efficiency. In this case, the presence of fluctuations, defined in training as intra-set or inter-repetition variability, will be essential to improving the efficiency of a given movement [3]. Fluctuations can appear in several forms. For example, a player learning to perform a pulley dismount on a conical pulley is likely to experience fluid movement due to coordination issues and a non-tensional rope, resulting in constant fluctuations. In a subject with experience in the movement, variation in speed or power will depend on fatigue-related factors, such as the accumulation of ammonia or hydrogen ions [87], rather than on a lack of motor control. However, the effects of perturbations on training adaptations remain unclear. This concept was initially explored in a study by Fitzgerald et al. [88], involving 26 individuals with ACL injury. These subjects were randomly assigned to either a traditional rehabilitation/readaptation group or a group that included perturbed tasks. Notably, in the perturbation group, 11 of 12 participants achieved satisfactory rehabilitation, whereas in the traditional group, only 50% successfully completed the program. These programs may increase the likelihood of successful outcomes rather than guaranteeing them. In recent years, a promising concept has emerged to address movement variability. Sample entropy is a marker of movement variability and, in practical terms, can help us determine whether the current exercise is producing fluctuations, irrespective of the presentation form used. For example, a group of experienced resistance-trained males performed squats under stable and unstable conditions, with measurements of both force and sample entropy [89]. After performing six sets of six repetitions, no differences were found in the mean force and force variability between conditions. In addition, another study assessed changes in movement variability and velocity after a 6-week training period using a resistance-based horizontal forward–backward task, with or without the constraint of catching and throwing a rugby ball during the forward phase [90]. Interestingly, movement velocity improved in both conditions, while sample entropy (i.e., movement variability) only significantly decreased in the ball condition. In summary, fluctuations can arise from various factors and do not necessarily indicate that the inclusion of a ball, a fitball, or unstable surfaces will directly cause them; they mainly depend on the subject's training background.

Furthermore, a study using advanced imaging techniques (computed tomography and magnetic resonance imaging) found that during learning of a new motor task, the primary motor cortex (M1) is activated, a pattern that disappears as the task becomes more familiar [91]. The M1 is responsible for the involvement of the brain-derived neurotrophic factor (BDNF) protein. This protein acts as a growth factor for neurotrophins, including nerve growth factor, and directly influences the development of synaptic plasticity in humans [92]. Therefore, if the objective is to facilitate continuous cortical-level development in athletes, including tasks with ongoing fluctuations, it may be beneficial.

In summary, incorporating decision-making demands and perturbations into training tasks may enhance cognitive and motor processes, potentially facilitating broader adaptive responses through task variability [90]. It is worth noting that football players are always looking for a movement competency when a perturbation is included. At that moment, it is time to increase movement difficulty using a new perturbation to develop corticospinal adaptations further.

Conclusions and Practical Recommendations

Improving, or even maintaining, athletic performance among competitive team-sport players during the long in-season period is one of the greatest challenges for any committed coach. Very limited time is available between weekly matches to implement intensive strength and power training sessions, typically 1–2 sessions per week. This fact spurs the quest for more efficient training methods that improve a wide range of functional abilities while avoiding carryover fatigue, primarily through a post-determined approach.

Thus, a training proposal should include several elements (i.e., variables) that can configure or shape football movements. Depending on the player's needs and functional deficits, it could be of interest to modulate the proportion of exercises, sort of like setting an equalizer, and tune between anteroposterior/lateral/rotational or

vertical movements, unilateral or bilateral exercises, variable or constant exercises. For example, players aiming to gain an advantage in jumping actions (e.g., heading, rebounding, spiking) may benefit more from incorporating vertical movements into their training sessions. In contrast, for players aiming to enhance forward/backward and lateral movements, training sessions should include a higher proportion of anteroposterior and lateral movements, with a greater focus on overloading the eccentric phase to support the ability to break and COD. Rotational movements are surely needed, but care must be taken, given the higher imposed loads [93]; hence, compensatory exercises (i.e., core stability and vibratory training) should be added to attenuate these aggressive loads.

Football and other situational sports are stochastic in nature, and players constantly adapt to new contexts. The inclusion of varied constraints through random, unanticipated, and unexpected executions may optimize the perceptual and cognitive mechanisms needed to interpret game situations better and reduce pre-motor time. "Predict the unpredictable" and "expect the unexpected" are useful watchwords repeated in football training sessions to spur and shape emergent functional behaviors in football players. As such, variability is a key factor to be introduced in a well-sequenced manner. In real training programs, just one set per exercise is performed, followed by two, four, or eight repetitions (reps) per set, with different movements in the concentric and eccentric phases. Furthermore, at the beginning, longer rest periods between exercises are used to maintain the ability to repeat power. As this ability improves, the time between exercises is reduced to achieve greater transfer to the demands of football. In addition, Hossner´s structural-learning proposal [94] regarding the need to link training content (e.g., movement) in accordance with the following might be used to determine an optimal degree of fluctuation across exercise progressions. In this way, elements such as instability, concurrent vibratory stimuli, unexpected and anti-phase movements, should be progressively incorporated into each movement family and direction (e.g., lunges, step-ups, diagonal chops, side-, cross-over, shuffling, drop or jab steps maneuvers…). Practitioners should consider incorporating these concepts into their football training schedules by alternating actions such as passing or heading a ball, jumping, turning, pushing or not against an opponent, and combining attack/defense situations, based on a specific stimulus to challenge the central nervous system, avoiding simple automatisms.

Abbreviations

1RM	One-repetition maximum
ACL	Anterior cruciate ligament
BDNF	Brain-derived neurotrophic factor
CK	Creatine kinase
CMJ	Countermovement jump
COD	Change of direction
EMG	Electromyography
ES	Effect size
M1	Primary motor cortex
RCOD	Repeated change of direction
RPA	Repeated power ability
RSA	Repeated sprint ability
$VO2_{max}$	Maximum oxygen consumption

Acknowledgements
The authors want to acknowledge the Spanish Ministry of Science and Innovation, the State Research Agency (AEI), and the European Union for supporting this research.

Author Contributions
OGS and JTF performed conceptualization, data curation, formal analysis, research, supervision, visualization, and manuscript writing (original draft and revision/editing). All authors read and approved the final version.

Funding
Oliver Gonzalo-Skok was supported by a Ramón y Cajal postdoctoral fellowship (RYC2023-045305-I) funded by MICIU/ AEI/10.13039/501100011033 and the FSE + given by the Spanish Ministry of Science and Innovation, the State Research Agency (AEI) and the European Union.

Data Availability
Not applicable.

Declarations

Ethics Approval and Consent to Participate
Not applicable.

Consent for Publication
Not applicable.

Competing Interests
The authors declare no conflicts of interest.

Received: 26 March 2026 Accepted: 4 August 2026
Published online: 18 August 2026

References

1. Julian R, Page RM, Harper LD. The effect of fixture congestion on performance during professional male soccer match-play: a systematic critical review with meta-analysis. Sports Med. 2021;51(2):255–73. https://doi.org/10.1007/s40279-020-01359-9.
2. Page RM, Field A, Langley B, Harper LD, Julian R. The effects of fixture congestion on injury in professional male soccer: a systematic review. Sports Med. 2022. https://doi.org/10.1007/s40279-022-01799-5.
3. Tous-Fajardo J. Strength training in elite football: An alternative approach. Sport Perform Sci Rep. 2019;(Striving for Excellence 2018):1–2.
4. Tous-Fajardo J, Gonzalo-Skok O, Arjol-Serrano JL, Tesch P. Enhancing change-of-direction speed in soccer players by functional inertial eccentric overload and vibration training. Int J Sports Physiol Perform. 2016;11(1):66–73. https://doi.org/10.1123/ijspp.2015-0010.
5. Besier TF, Lloyd DG, Ackland TR, Cochrane JL. Anticipatory effects on knee joint loading during running and cutting maneuvers. Med Sci Sports Exerc. 2001. https://doi.org/10.1097/00005768-200107000-00015.
6. Gonzalo-Skok O, Tous-Fajardo J, Valero-Campo C, et al. Eccentric-overload training in team-sport functional performance: constant bilateral vertical versus variable unilateral multidirectional movements. Int J Sports Physiol Perform. 2017;12(7):951–8. https://doi.org/10.1123/ijspp.2016-0251.

7. Krosshaug T, Nakamae A, Boden BP, et al. Mechanisms of anterior cruciate ligament injury in basketball. Am J Sports Med. 2007;35(3):359–67. https://doi.org/10.1177/0363546506293899.
8. Sabido R, Hernández-Davó JL, Botella J, Moya M. Effects of 4-week training intervention with unknown loads on power output performance and throwing velocity in junior team handball players. PLoS ONE. 2016;11(6):e0157648. https://doi.org/10.1371/journal.pone.0157648.
9. Leventer L, Dicks M, Duarte R, Davids K, Araújo D. Emergence of contact injuries in invasion team sports: an ecological dynamics rationale. Sports Med. 2015;45(2):153–9. https://doi.org/10.1007/s40279-014-0263-x.
10. Contreras B, Vigotsky AD, Schoenfeld BJ, et al. Effects of a six-week hip thrust vs. front squat resistance training program on performance in adolescent males: a randomized controlled trial. J Strength Cond Res. 2017;31(4):999–1008. https://doi.org/10.1519/JSC.0000000000001510.
11. Sánchez-Sabaté J, Gutiérrez H, Marco-Contreras LA, Younes-Egana O, Gonzalo-Skok O, Piedrafita E. Influence of vertical-oriented vs. horizontal-oriented combined strength training in young basketball players. J Strength Cond Res. 2024. https://doi.org/10.1519/JSC.0000000000004771.
12. Gonzalo-Skok O, Sánchez-Sabaté J, Tous-Fajardo J, Mendez-Villanueva A, Bishop C, Piedrafita E. Effects of direction-specific training interventions on physical performance and inter-limb asymmetries. Int J Environ Res Public Health. 2022;19(3):1029. https://doi.org/10.3390/ijerph19031029.
13. Buchheit M, Samozino P, Glynn JA, et al. Mechanical determinants of acceleration and maximal sprinting speed in highly trained young soccer players. J Sports Sci. 2014;32(20):1906–13. https://doi.org/10.1080/02640414.2014.965191.
14. Rabita G, Dorel S, Slawinski J, et al. Sprint mechanics in world-class athletes: a new insight into the limits of human locomotion. Scand J Med Sci Sports. 2015;25(5):583–94. https://doi.org/10.1111/sms.12389.
15. Brazil A, Needham L, Palmer JL, Bezodis IN. A comprehensive biomechanical analysis of the barbell hip thrust. PLoS ONE. 2021;16(3):e0249307. https://doi.org/10.1371/journal.pone.0249307.
16. Fitzpatrick D, Cimadoro G, Cleather D. The magical horizontal force muscle? A preliminary study examining the "force-vector" theory. Sports. 2019;7(2):30. https://doi.org/10.3390/sports7020030.
17. Meinerz CM, Malloy P, Geiser CF, Kipp K. Anticipatory effects on lower extremity neuromechanics during a cutting task. J Athl Train. 2015;50(9):905–13. https://doi.org/10.4085/1062-6050-50.8.02.
18. Malloy PJ, Morgan AM, Meinerz CM, Geiser CF, Kipp K. Hip external rotator strength is associated with better dynamic control of the lower extremity during landing tasks. J Strength Cond Res. 2016;30(1):282–91. https://doi.org/10.1519/JSC.0000000000001069.
19. Khayambashi K, Ghoddosi N, Straub RK, Powers CM. Hip muscle strength predicts noncontact anterior cruciate ligament injury in male and female athletes. Am J Sports Med. 2016;44(2):355–61. https://doi.org/10.1177/0363546515616237.
20. Núñez-González JL, Gonzalo-Skok O, García MJ, Hernández Abad F, Núñez FJ. Effects of sidestep exercise with elastic bands on multidirectional speed abilities and navicular drop in young male football players: a randomized cross-over trial. Appl Sci. 2025;15(6):2892. https://doi.org/10.3390/app15062892.
21. Zhang F, Liu Y, Shi S, Wang H, Liu J, Yeremenko O. Comparative effects of unilateral and bilateral plyometric training on physical fitness in adolescent team-sport athletes: a systematic review and meta-analysis. Front Physiol. 2026. https://doi.org/10.3389/fphys.2026.1820331.
22. Zhang Z, Qu W, Peng W, et al. Effect of unilateral and bilateral plyometric training on jumping, sprinting, and change of direction abilities: a meta-analysis. BMC Sports Sci Med Rehabil. 2025;17(1):97. https://doi.org/10.1186/s13102-025-01113-6.
23. Gustavsson A, Neeter C, Thomeé P, et al. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2006;14(8):778–88. https://doi.org/10.1007/s00167-006-0045-6.
24. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery. Am J Sports Med. 2011;39(3):538–43. https://doi.org/10.1177/0363546510384798.
25. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41(1):3–12. https://doi.org/10.1249/MSS.0b013e31818cb278.
26. Brown SR, Feldman ER, Cross MR, et al. The potential for a targeted strength-training program to decrease asymmetry and increase performance: a proof of concept in sprinting. Int J Sports Physiol Perform. 2017;12(10):1392–5. https://doi.org/10.1123/ijspp.2016-0590.
27. Gonzalo-Skok O, Tous-Fajardo J, Suarez-Arrones L, Arjol-Serrano JL, Casajús JA, Mendez-Villanueva A. Single-leg power output and between-limbs imbalances in team-sport players: unilateral versus bilateral combined resistance training. Int J Sports Physiol Perform. 2017;12(1):106–14. https://doi.org/10.1123/ijspp.2015-0743.
28. Sun W, Li H, Qu L, et al. Unilateral plyometric training effectively reduces lower limb asymmetry in athletes: a meta-analysis. Front Physiol. 2025. https://doi.org/10.3389/fphys.2025.1551523.
29. Liao KF, Nassis G, Bishop C, Yang W, Bian C, Li YM. Effects of unilateral vs. bilateral resistance training interventions on measures of strength, jump, linear and change of direction speed: a systematic review and meta-analysis. Biol Sport. 2022;39(3):485–97. https://doi.org/10.5114/biolsport.2022.107024.
30. Moran J, Ramirez-Campillo R, Liew B, et al. Effects of bilateral and unilateral resistance training on horizontally orientated movement performance: a systematic review and meta-analysis. Sports Med. 2021;51(2):225–42. https://doi.org/10.1007/s40279-020-01367-9.
31. Tous-Fajardo J, Maldonado RA, Quintana JM, Pozzo M, Tesch PA. The flywheel leg-curl machine: offering eccentric overload for hamstring development. Int J Sports Physiol Perform. 2006;1(3):293–8. https://doi.org/10.1123/ijspp.1.3.293.
32. Russell M, Sparkes W, Northeast J, et al. Changes in acceleration and deceleration capacity throughout professional soccer match-play. J Strength Cond Res. 2016;30(10):2839–44. https://doi.org/10.1519/JSC.0000000000000805.
33. Akenhead R, Hayes PR, Thompson KG, French D. Diminutions of acceleration and deceleration output during professional football match play. J Sci Med Sport. 2013;16(6):556–61. https://doi.org/10.1016/j.jsams.2012.12.005.
34. Varley I, Lewin R, Needham R, Thorpe RT, Burbeary R. Association between match activity variables, measures of fatigue and neuromuscular performance capacity following elite competitive soccer matches. J Hum Kinet. 2017;60(1):93–9. https://doi.org/10.1515/hukin-2017-0093.
35. Jindrich DL, Besier TF, Lloyd DG. A hypothesis for the function of braking forces during running turns. J Biomech. 2006;39(9):1611–20. https://doi.org/10.1016/j.jbiomech.2005.05.007.
36. Spiteri T, Newton RU, Binetti M, Hart NH, Sheppard JM, Nimphius S. Mechanical determinants of faster change of direction and agility performance in female basketball athletes. J Strength Cond Res. 2015;29(8):2205–14. https://doi.org/10.1519/JSC.0000000000000876.
37. Dos'Santos T, Thomas C, Jones PA, Comfort P. Mechanical determinants of faster change of direction speed performance in male athletes. J Strength Cond Res. 2017;31(3):696–705. https://doi.org/10.1519/JSC.0000000000001535.
38. de Hoyo M, de la Torre A, Pradas F, et al. Effects of eccentric overload bout on change of direction and performance in soccer players. Int J Sports Med. 2014;36(04):308–14. https://doi.org/10.1055/s-0034-1395521.
39. de Hoyo M, Pozzo M, Sañudo B, et al. Effects of a 10-week in-season eccentric-overload training program on muscle-injury prevention and performance in junior elite soccer players. Int J Sports Physiol Perform. 2015;10(1):46–52. https://doi.org/10.1123/ijspp.2013-0547.
40. de Hoyo M, Sañudo B, Carrasco L, et al. Effects of 10-week eccentric overload training on kinetic parameters during change of direction in football players. J Sports Sci. 2016;34(14):1380–7. https://doi.org/10.1080/02640414.2016.1157624.
41. de Paula Simola RÁ, Harms N, Raeder C, et al. Assessment of neuromuscular function after different strength training protocols using tensiomyography. J Strength Cond Res. 2015;29(5):1339–48. https://doi.org/10.1519/JSC.0000000000000768.
42. Sabido R, Hernández-Davó JL, Botella J, Navarro A, Tous-Fajardo J. Effects of adding a weekly eccentric-overload training session on strength and athletic performance in team-handball players. Eur J Sport Sci. 2017;17(5):530–8. https://doi.org/10.1080/17461391.2017.1282046.
43. de Dios-Álvarez V, Rey E, Padrón-Cabo A, Castellano J. Impact of weekly eccentric overload training on locomotor and mechanical performance in youth soccer players. J Sports Sci Med. 2025. https://doi.org/10.52082/jssm.2025.351.

44. Manolopoulos E, Papadopoulos C, Kellis E. Effects of combined strength and kick coordination training on soccer kick biomechanics in amateur players. Scand J Med Sci Sports. 2006;16(2):102–10. https://doi.org/10.1111/j.1600-0838.2005.00447.x.
45. Raya-González J, Prat-Luri A, López-Valenciano A, Sabido R, Hernández-Davó J. Effects of flywheel resistance training on sport actions. A systematic review and meta-analysis. J Hum Kinet. 2021;77:191–204. https://doi.org/10.2478/hukin-2021-0020.
46. Hu Z, Liu Y, Huang K, Huang H, Li F, Yuan X. Comparing the effect of isoinertial flywheel training and traditional resistance training on maximal strength and muscle power in healthy people: a systematic review and meta-analysis. Life. 2024;14(7):908. https://doi.org/10.3390/life14070908.
47. Dou Y, Zhang W, Xu H, et al. Unilateral flywheel training enhances eccentric braking capacity, change-of-direction performance, and match acceleration–deceleration in soccer players. Appl Sci (Basel). 2026;16(4):2134. https://doi.org/10.3390/app16042134.
48. Morton RH, Fitz-Clarke JR, Banister EW. Modeling human performance in running. J Appl Physiol. 1990;69(3):1171–7. https://doi.org/10.1152/jappl.1990.69.3.1171.
49. Modric T, Carling C, Lago-Peñas C, Versic Š, Morgans R, Sekulic D. To train or not to train (on match day)? Influence of a priming session on match performance in competitive elite-level soccer. J Sports Sci. 2023;41(18):1726–33. https://doi.org/10.1080/02640414.2023.2296741.
50. Randell AD, Cronin JB, Keogh JWL, Gill ND, Pedersen MC. Effect of instantaneous performance feedback during 6 weeks of velocity-based resistance training on sport-specific performance tests. J Strength Cond Res. 2011;25(1):87–93. https://doi.org/10.1519/JSC.0b013e3181fee634.
51. Orange ST, Hritz A, Pearson L, Jeffries O, Jones TW, Steele J. Comparison of the effects of velocity-based vs. traditional resistance training methods on adaptations in strength, power, and sprint speed: a systematic review, meta-analysis, and quality of evidence appraisal. J Sports Sci. 2022;40(11):1220–34. https://doi.org/10.1080/02640414.2022.2059320.
52. Forelli F, Marine P, Moiroux-Sahraoui A, et al. Velocity-based training in mid- and late-stage rehabilitation after anterior cruciate ligament reconstruction: a narrative review and practical guidelines. BMJ Open Sport Exerc Med. 2025;11(2):e002503. https://doi.org/10.1136/bmjsem-2025-002503.
53. Jukic I, Castilla AP, Ramos AG, Van Hooren B, McGuigan MR, Helms ER. The acute and chronic effects of implementing velocity loss thresholds during resistance training: a systematic review, meta-analysis, and critical evaluation of the literature. Sports Med. 2023;53(1):177–214. https://doi.org/10.1007/s40279-022-01754-4.
54. Weakley JJS, Wilson KM, Till K, et al. Visual feedback attenuates mean concentric barbell velocity loss and improves motivation, competitiveness, and perceived workload in male adolescent athletes. J Strength Cond Res. 2019;33(9):2420–5. https://doi.org/10.1519/JSC.0000000000002133.
55. Pérez-Castilla A, Jiménez-Alonso A, Cepero M, Miras-Moreno S, Rojas FJ, García-Ramos A. Velocity performance feedback during ballistic training: which is the optimal frequency of feedback administration? Mot Control. 2021;25(1):19–32. https://doi.org/10.1123/mc.2020-0039.
56. Weakley J, Cowley N, Schoenfeld BJ, et al. The effect of feedback on resistance training performance and adaptations: a systematic review and meta-analysis. Sports Med. 2023;53(9):1789–803. https://doi.org/10.1007/s40279-023-01877-2.
57. Tidow G. Muscular adaptations induced by training and de-training-a review of biopsy studies. New studies in athletics. 1995;10(2):47–56.
58. Gonzalo-Skok O, Tous-Fajardo J. Power loss minimization through maximal power endurance or repeated power training programs. Int J Sports Physiol Perform. 2025;20(3):463–72. https://doi.org/10.1123/ijspp.2024-0200.
59. Castagna C, Manzi V, D'Ottavio S, Annino G, Padua E, Bishop D. Relation between maximal aerobic power and the ability to repeat sprints in young basketball players. Jo Strength Condition Res. 2007;21(4):1172. https://doi.org/10.1519/R-20376.1.
60. Ben Abdelkrim N, Castagna C, El Fazaa S, El Ati J. The effect of players' standard and tactical strategy on game demands in men's basketball. J Strength Cond Res. 2010;24(10):2652–62. https://doi.org/10.1519/JSC.0b013e3181e2e0a3.
61. Ben Abdelkrim N, Castagna C, Jabri I, Battikh T, El Fazaa S, Ati JE. Activity profile and physiological requirements of junior elite basketball players in relation to aerobic-anaerobic fitness. J Strength Cond Res. 2010;24(9):2330–42. https://doi.org/10.1519/JSC.0b013e3181e381c1.
62. Ben Abdelkrim N, El Fazaa S, El Ati J, Tabka Z. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition * Commentary. Br J Sports Med. 2007;41(2):69–75. https://doi.org/10.1136/bjsm.2006.032318.
63. Gleeson NP, Reilly T, Mercer TH, Rakowski S, Rees D. Influence of acute endurance activity on leg neuromuscular and musculoskeletal performance. Med Sci Sports Exerc. 1998;30(4):596–608. https://doi.org/10.1097/00005768-199804000-00019.
64. Hader K, Mendez-Villanueva A, Ahmaidi S, Williams BK, Buchheit M. Changes of direction during high-intensity intermittent runs: neuromuscular and metabolic responses. BMC Sports Sci Med Rehabil. 2014;6(1):2. https://doi.org/10.1186/2052-1847-6-2.
65. Suarez-Arrones L, Tous-Fajardo J, Núñez J, Gonzalo-Skok O, Gálvez J, Mendez-Villanueva A. Concurrent repeated-sprint and resistance training with superimposed vibrations in rugby players. Int J Sports Physiol Perform. 2014;9(4):667–73. https://doi.org/10.1123/ijspp.2013-0238.
66. Gonzalo-Skok O, Tous-Fajardo J, Arjol-Serrano JL, Suarez-Arrones L, Casajús JA, Mendez-Villanueva A. Improvement of repeated-sprint ability and horizontal-jumping performance in elite young basketball players with low-volume repeated-maximal-power training. Int J Sports Physiol Perform. 2016;11(4):464–73. https://doi.org/10.1123/ijspp.2014-0612.
67. Gonzalo-Skok O, Tous-Fajardo J, Moras G, Arjol-Serrano JL, Mendez-Villanueva A. A repeated power training enhances fatigue resistance while reducing intraset fluctuations. J Strength Cond Res. 2019;33(10):2711–21. https://doi.org/10.1519/JSC.0000000000002541.
68. Arede J, Leite N, Tous-Fajardo J, Bishop C, Gonzalo-Skok O. Enhancing high-intensity actions during a basketball game after a strength training program with random recovery times between sets. J Strength Cond Res. 2022;36(7):1989–97. https://doi.org/10.1519/JSC.0000000000004002.
69. Ryan S, Browne D, Ramirez-Campillo R, Moody J, Byrne PJ. The acute effect of different cluster set intra-set rest interval configurations on mechanical power measures during a flywheel resistance training session. Sports (Basel). 2024;12(12):324. https://doi.org/10.3390/sports12120324.
70. Lloyd DG. Rationale for training programs to reduce anterior cruciate ligament injuries in Australian football. J Orthop Sports Phys Ther. 2001;31(11):645–54. https://doi.org/10.2519/jospt.2001.31.11.645.
71. Sell TC, Ferris CM, Abt JP, et al. The effect of direction and reaction on the neuromuscular and biomechanical characteristics of the knee during tasks that simulate the noncontact anterior cruciate ligament injury mechanism. Am J Sports Med. 2006;34(1):43–54. https://doi.org/10.1177/0363546505278696.
72. Brown TN, Palmieri-Smith RM, McLean SG. Sex and limb differences in hip and knee kinematics and kinetics during anticipated and unanticipated jump landings: implications for anterior cruciate ligament injury. Br J Sports Med. 2009;43(13):1049–56. https://doi.org/10.1136/bjsm.2008.055954.
73. Borotikar BS, Newcomer R, Koppes R, McLean SG. Combined effects of fatigue and decision making on female lower limb landing postures: central and peripheral contributions to ACL injury risk. Clin Biomech. 2008;23(1):81–92. https://doi.org/10.1016/j.clinbiomech.2007.08.008.
74. Kipp K, Brown TN, McLean SG, Palmieri-Smith RM. Decision making and experience level influence frontal plane knee joint biomechanics during a cutting maneuver. J Appl Biomech. 2013;29(6):756–62. https://doi.org/10.1123/jab.29.6.756.
75. Cochrane JL, Lloyd DG, Besier TF, Elliott BC, Doyle TLA, Ackland TR. Training affects knee kinematics and kinetics in cutting maneuvers in sport. Med Sci Sports Exerc. 2010;42(8):1535–44. https://doi.org/10.1249/MSS.0b013e3181d03ba0.
76. Romero-Rodríguez D, Tous-Fajardo J. Prevención de Lesiones En El Deporte: Claves Para Un Rendimiento Deportivo Óptimo. Editorial Médica Panamericana; 2011.
77. Zebis MK, Andersen LL, Bencke J, Kjær M, Aagaard P. Identification of athletes at future risk of anterior cruciate ligament ruptures by neuromuscular screening. Am J Sports Med. 2009;37(10):1967–73. https://doi.org/10.1177/0363546509335000.
78. Zebis MK, Andersen LL, Brandt M, et al. Effects of evidence-based prevention training on neuromuscular and biomechanical risk factors for ACL injury in adolescent female athletes: a randomised controlled

trial. Br J Sports Med. 2016;50(9):552–7. https://doi.org/10.1136/bjsports-2015-094776.
79. Dux PE, Tombu MN, Harrison S, Rogers BP, Tong F, Marois R. Training improves multitasking performance by increasing the speed of information processing in human prefrontal cortex. Neuron. 2009;63(1):127–38. https://doi.org/10.1016/j.neuron.2009.06.005.
80. Martin V, Sanchez-Sanchez J, Ramírez-Campillo R, Nakamura F, Gonzalo-Skok O. Validity of the RSA-RANDOM test for young soccer players. Int J Sports Med. 2018;39(11):813–21. https://doi.org/10.1055/a-0637-2094.
81. Gonzalo-Skok O, Tous-Fajardo J, Maroto-Izquierdo S, Raya-González J, Sánchez-Sánchez J. The inclusion of preplanned and random and unanticipated/unexpected events during strength training improves the ability to repeat high-intensity efforts under uncertainty. Int J Sports Physiol Perform. 2024;19(3):249–56. https://doi.org/10.1123/ijspp.2023-0107.
82. Hernández-Davo H, Urbán T, Sarabia JM, Juan-Recio C, Javier Moreno F. Variable training: effects on velocity and accuracy in the tennis serve. J Sports Sci. 2014;32(14):1383–8. https://doi.org/10.1080/02640414.2014.891290.
83. Hernández-Davó JL, Sabido R, Moya-Ramón M, Blazevich AJ. Load knowledge reduces rapid force production and muscle activation during maximal-effort concentric lifts. Eur J Appl Physiol. 2015;115(12):2571–81. https://doi.org/10.1007/s00421-015-3276-8.
84. Hernández-Davó JL, Sabido R, Behm DG, Blazevich AJ. Effects of resistance training using known vs unknown loads on eccentric-phase adaptations and concentric velocity. Scand J Med Sci Sports. 2018;28(2):407–17. https://doi.org/10.1111/sms.12933.
85. Powell DW, Williams DSB. Athletes trained using stable compared to unstable surfaces exhibit distinct postural control profiles when assessed by traditional and nonlinear measures. Hum Mov Sci. 2015;44:73–80. https://doi.org/10.1016/j.humov.2015.08.013.
86. Anderson KG, Behm DG. Maintenance of EMG activity and loss of force output with instability. J Strength Condition Res. 2004;18(3):637. https://doi.org/10.1519/1533-4287(2004)18%3c637:MOEAAL%3e2.0.CO;2.
87. Sánchez-Medina L, González-Badillo JJ. Velocity loss as an indicator of neuromuscular fatigue during resistance training. Med Sci Sports Exerc. 2011;43(9):1725–34. https://doi.org/10.1249/MSS.0b013e318213f880.
88. Fitzgerald GK, Axe MJ, Snyder-Mackler L. The efficacy of perturbation training in nonoperative anterior cruciate ligament rehabilitation programs for physical active individuals. Phys Ther. 2000;80(2):128–40.
89. Moras G, Vázquez-Guerrero J, Fernández-Valdés B, et al. Structure of force variability during squats performed with an inertial flywheel device under stable versus unstable surfaces. Hum Mov Sci. 2019;66:497–503. https://doi.org/10.1016/j.humov.2019.05.022.
90. Fernández-Valdés B, Sampaio J, Exel J, et al. The influence of functional flywheel resistance training on movement variability and movement velocity in elite rugby players. Front Psychol. 2020. https://doi.org/10.3389/fpsyg.2020.01205.
91. Dayan E, Cohen LG. Neuroplasticity subserving motor skill learning. Neuron. 2011;72(3):443–54. https://doi.org/10.1016/j.neuron.2011.10.008.
92. Lu B. Pro-region of neurotrophins. Neuron. 2003;39(5):735–8. https://doi.org/10.1016/S0896-6273(03)00538-5.
93. Kawamoto R, Ishige Y, Watarai K, Fukashiro S. Quantitative investigation of torsional loading of the tibia during quick change of running direction. Int J Sport Health Sci. 2003;1(1):24–33. https://doi.org/10.5432/ijshs.1.24.
94. Hossner EJ, Käch B, Enz J. On the optimal degree of fluctuations in practice for motor learning. Hum Mov Sci. 2016;47:231–9. https://doi.org/10.1016/j.humov.2015.06.007.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.