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The effects of two preseason periodizations on peak torque of knee extensors and flexors of a Polish first league soccer team

Miłosz Drozd[1,4]✉, Jakub Jarosz[1], Mariola Gepfert[1], Jose Antonio Perez Turpin[2], Adam Zając[1], Michał Spieszny[3] & Justyna Michalska[1]

The study aimed to compare the effectiveness of two resistance training load progression methods—linear and step—on peak torque and power of knee extensors and flexors during the preseason of a Polish First League soccer team across two seasons. Differences between dominant and non-dominant limbs were analyzed, with progression tracked by tempo of movement and time under tension. Velocity-based training with a linear transducer ensured standardized intensity. Sixteen players from the same club participated in both seasons: 2021/2022 (linear) and 2022/2023 (step). Three-way ANOVA showed a significant leg × training × mesocycle interaction in the knee extensor and flexor peak torque. The post hoc test showed significant differences in peak torque between the dominant and nondominant legs during both progressive load methods – 2021/2022 and 2022/2023 seasons, both before and after the training intervention ($p < 0.05$). Knee extensors: The dominant leg showed higher values compared to the non-dominant leg. However, there were no significant differences during the 2022/2023 season ($p > 0.05$). Knee flexors: No difference in peak torque values between the dominant and non-dominant legs before the training intervention – 2022/2023 season. The conducted studies clearly indicate a greater effectiveness of the step load progression, however it also significantly affected bilateral asymmetry.

Keywords Movement tempo, Velocity-based training, Preseason, Dominant limb, Nondominant limb, Inter-limb asymmetries

Monitoring training loads and frequent assesment of fitness results are key factors in optimizing the periodization of sports training[1]. In soccer, periodization is largely dependent on the schedule of games and the time between rounds. In each country and league the competition schedule is different[1–3]. In Poland, at the central level, the II and I leagues (Befor *Fortuna I liga*/ Now *Betclic 1 liga*) usually have a longer preparation period of about 1–2 weeks compared to the Ekstraklasa (the top league). Very often, the length of the pre-season is also influenced by international soccer events such as the European or World Championships. Therefore, considering that achieving a championship level is a long-term process, innovative training methods are increasingly used to maximize the athlete's motor performance. Hence, periodization of the training program is a key element that determines the optimization of individual micro- and mesocycles of training. Therefore, appropriate monitoring of variables in periodization such as load, bar velocity, number of repetitions and sets, as well as movement tempo, as well as rest intervals between sets have a direct impact on the effectiveness of the training process[4]. Taking into account the beginning of the competitive season and the length of particular rounds and the cyclicality of matches (usually 1 championship match every 7 days), it is assumed that the microcycle in soccer consists of 7 days, especially in the competitive period. Only occasionally is it extended or shortened (break for the national team match, schedule change due to TV broadcast of a match), which allows us to conclude that most teams carry out 1 to 2 strength training sessions in a microcycle[1–3]. Pre-seasson in soccer allows for the implementation of various types of resistance training load progression within specific mesocycles. When combined with locomotion monitoring

[1]Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland. [2]Department: General Didactic and Specific Didactic, Institute: I.U. Tourist Research, University of Alicante, Alicante, Spain. [3]Department of Sports Theory, Sports Training Facility, Institute of Sports Sciences, University of Physical Education in Krakow, Kraków, Poland. [4]Department of Sports Theory, The Jerzy Kukuczka Academy of Physical Education, Sports Training Facility, Katowice, Poland. ✉email: m.drozd@awf.katowice.pl

using GPS devices, this enables the strategic planning of accumulation and supercompensation phases within the mesocycle[4,5]. As a result, the number of soccer training sessions per microcycle increases, reaching up to 6–10 sessions. Additionally, depending on the microcycle structure, one to two resistance training sessions are typically observed. The entire microcycle usually ends with a friendly match. As Stone et al.[6] suggested, a lack of training variation can lead to monotonous overtraining. Therefore, it is crucial to optimize load progression, training frequency and the resistance training volume during the pre-session to enhance and maintain strength and power while minimizing interference with soccer specific skills. This raises an important question for many coaches: "What periodization method for resistance training should be used? what training variables should be monitored to properly prepare the team for competition by inducing favorable adaptations while ensuring that resistance training does not significantly compromise the effectiveness of technical and tactical tasks in soccer training?

Soccer is a complex sport that involves a combination of activities, including steady-state running, sprints, changes of direction, jumping, passing, and striking the ball, all while implementing tactical strategies. Very often, many of these activities involved in soccer competition contribute to unilateral limb dominance in terms of muscle strength and power[7]. Muscle asymmetry between the quadriceps and hamstrings muscles in the dominant (D) and non-dominant (ND) limbs may increase the likelihood of injury, particularly to hamstring strains and anterior cruciate ligament injury[8,9]. In men's soccer, the hamstrings are the most frequently injured muscle group[10]. Interestingly, about 96% of these injuries occur without direct contact[11]. Therefore, the goal of resistance training in soccer is not solely to increase muscle strength but also to reduce muscle imbalances, improve neuromuscular coordination, and enhance injury prevention strategies. Additionally, periodized resistance training plays a crucial role in balancing strength development while minimizing interference with technical and tactical training.

Therefore, the objective of this study was to compare the effectiveness of two mesocycles with different load progression in enhancing relative peak torque and peak power of knee extensors and flexors of the lower extremities during the preseason among a Polish First League soccer team over two seasons. The analysis considered the differences between the D and ND limbs, with volume progression assessed based on movement tempo and TUT. To ensure standardized training load intensity, velocity-based training (VBT) was employed using a linear transducer. This approach allowed for precise monitoring of training intensity and volume while enabling individualization, such as adjusting the percentage of one-repetition maximum (%1RM) based on movement tempo, TUT, and the athlete's current condition[2]. This approach was particularly utilized in the second preseason to optimize training adaptations. It was hypothesized that step-load periodization would result in greater improvements in relative peak torque and relative peak power of knee extensors and flexors compared to linear periodization. This effect was expected due to the initiation of the primary accumulation phase in the third microcycle, which occurs immediately before the deloading phase and may facilitate more effective supercompensation. Additionally, it was anticipated that both step-load and linear periodization would not significantly influence muscle asymmetry between the dominant and non-dominant lower limbs.

Materials and methods

Experimental approach to the problem

To determine the effect of two different load progression in resistance training on relative peak power and peak torque of knee extensors and flexors, a 3:1 step load (with 1 indicating an unloading phase) was applied. Isokinetic testing was conducted at the beginning and at the end of each preseason period to assess relative peak power and peak torque of knee extensors and flexors. First, it should be noted that the period preceding both pre-season mesocycles was identical in terms of resistance training structure (%1RM, TUT, movement tempo, sets, repetitions, rest intervals between sets as well as types and order of exercises) and running training. The training schedule remained the same in both seasons, with all participants performing 3 strength training and 3 running training sessions at the same intervals. The only difference between the two pre-seasons was the length of the interval between competition rounds, which lasted 12 weeks in the 2021/2022 season and 15 weeks in the 2022/2023 season due to the FIFA World Cup in Qatar.

Participants

The study used direct selection of participants which included 16 soccer players (mean (± standard deviation) age: 27 ± years, body mass: 79 ± kg, height: 172 ± cm) who represented the same club in the 2021/2022 and 2022/2023 seasons at the central level of the Polish First League. Participants refrained from engaging in resistance training for at least 72 h prior to each testing session to minimize the potential influence of residual fatigue on outcomes. The athletes were informed about the procedure of the experiment and its purpose. Each subject gave his written consent to participate in the study. The study was conducted in accordance with the Declaration of Helsinki, and approved by the Bioethics Committee for Scientific Research (03/2021/Dz. U. 1999 Nr 47, poz. 480) at the Academy of Physical Education in Katowice. The experiments complied with the current laws of the country in which they were performed.

Resistance training protocol and periodization

The preseason training program was designed to compare two different periodization models: step-load periodization (Season 2021/2022) and linear-load periodization (Season 2022/2023). Both training programs lasted four microcycles and were followed by a tapering phase leading up to a championship match. In each season, athletes participated in three resistance training sessions and three running sessions per week, with training intensity and volume adjusted according to the respective periodization model. Figures 1 and 2 illustrate the mesocycle structure for each season, while Figs. 3 and 4 provide details on movement tempo and loading strategies.

SEASON 2021/2022																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
XII				M	F																										
I	F	R	F	S	F	S	F	R	F	F	R	F	S	F	R	F	S	F			1 MICROCYCLE							2 MICROCYCLE			
II				3 MICROCYCLE							4 MICROCYCLE							TAPERING									M				

Fig. 1. Mesocycle construction during the season 2021/2022. M- Championship Match; F - free; S - strength training; R - running.

SEASON 2022/2023																															
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
XI											M	F																			
XII	F																			R	F	S	F	R	S	F	R	F	S	F	R
I	F	S	F			1 MICROCYCLE							2 MICROCYCLE							3 MICROCYCLE							4 MICROCYCLE				
II			TAPERING									M																			

Fig. 2. Mesocycle construction during the season 2022/2023. M- Championship Match; F - free; S - strength training; R - running.

Fig. 3. Step-load periodization implemented in the 2021/2022 season. Tempo of movement (3/0/2/0) eccentric/isometric/concentric/isometric phases of each repetition/X-maximum voluntary velocity.

1. Step load season 2021/2022-Break between rounds 12 weeks (Fig. 1).

- Baseline tests- January 2022.
- Final tests after 4 microcycles (1 microcycle = 7 days).
- End of the step load mesocycle 10 days to the championship match.

2. Linear load season 2022/2023-Break between rounds of 15 weeks (Fig. 2).

- Baseline tests- January 2023.
- Final tests after 4 microcycles (1 microcycle = 7 days).
- At the end of the step, load the mesocycle 10 days to the championship match.

The training load in exercises such as the barbell squat (high bar), reverse lunge (high bar), and bench press was selected through velocity-based training (VBT), which was determined using the Tendo Power Analyzer linear

Fig. 4. Linear load periodization implemented in the 2022/2023 season. Tempo of movement (3/0/2/0) eccentric/isometric/concentric/isometric phases of each repetition/X-maximum voluntary velocity.

Exercise	Velocity (m/s)	Repetitions (*n*)	Sets (*n*)		Rest interval between Sets (s)	Rest interval between exercises (s)
			Monday 9:00 a.m.	Thursday 9:00 a.m.		
Barbell Squat (high bar)	1-0.75	5	4	2	100	180
Bench Press	1-0.75	5 (5 per side)	4	2	100	180
Reverse Lunge (high bar)	1-0.75	5	4	2	100	180
Australian Pull-up with Swiss Ball	Accessory exercise	10	4	2	100	180
Hamstring Swiss Ball Curls	Accessory exercise	10	4	2	100	180

Table 1. Resistance training description.

Season 2021/2022					
Microcycle Number	Microcycle Tempo	Time under Tension-Exercise (s)	Time under Tension -Training session (s)		Time under Tension - Microcycle (s)
			Monday	Thursday	
1	3/0/X/0	60	480	240	720
2	4/0/X/0	80	640	320	960
3	5/0/X/0	100	800	400	1200
4	2/0/X/0	40	320	160	480
Season 2022/2023					
Microcycle Number	Microcycle Tempo	Time under Tension-Exercise (s)	Time under Tension -Training session (s)		Time under Tension - Microcycle (s)
			Monday	Thursday	
1	5/0/X/0	100	800	400	1200
2	4/0/X/0	80	640	320	960
3	3/0/X/0	60	480	240	720
4	2/0/X/0	40	320	160	480

Table 2. Time under tension variables across microcycles.

position transducer (Tendo Sport Machines, Trencin, Slovakia), on which the entire training process was based (Table 1). Therefore, in these exercises, athletes had to achieve appropriate VBT values (1–0.75 m/s) each time, which corresponds to 50–60% of 1RM. The remaining supplementary exercises were based on a specific number of repetitions, depending on the movement tempo and TUT in the particular step load microcycles (Table 2).

Strength and power assessments

Measurements were taken under standard conditions, that is, during the morning hours (8 to 9 am), with 72 h of restriction from training and consumption of alcohol and caffeine. The relative peak torque and power of knee extensors and flexors were tested using an "isokinetic device" (HUMAC NORM, Stoughton, MA, USA)[12]. The tests were carried out in the presence of the coaching staff who supervised the tests, and the entire procedure was carried out by a technical employee of the university familiar with the device. Particular muscle groups activated under concentric work conditions (muscle shortening) with isokinetic (constant angular velocity) under laboratory conditions were evaluated. The device was calibrated according to the manufacturer's instructions[12]. Before the test, participants performed a 10 min warm-up on a cycle ergometer (Keiser M3i, Fresno, CA, USA) at a cadence of 70–80 RPM. To familiarize themselves with the testing procedures, the subjects performed three submaximal and two maximal repetitions (60°/s) before the main test. A 30 s rest interval was given between repetitions, and a 3 min rest interval was provided between sets[13]. Before the test began, verbal instructions were given to generate as much force and power as possible during the test. Furthermore, no verbal encouragement was used during the test, but a computer screen was set so that participants could receive real-time feedback. The participants were seated in an extended position, with the backrest at an angle of 85°. The axis of rotation of the knee joint was placed in line with the axis of rotation of the dynamometer. The lever arm pad was fixed at the head of the fibula so that movement of the ankle joint was not restricted. The tests were carried out within a predefined range of motion (90–0°). To minimize compensatory trunk movements during the test, participants were secured using stabilizing straps, according to the manufacturer's instructions[12]. The athletes performed a test of five repetitions of knee flexion and extension at 60°/s in the concentric and eccentric muscle action modes.

Because peak torque and peak power were expressed in terms of fat free mass (FFM). This value was expressed using the formula:

$$\text{FFM} = \text{TBM-FM}$$

FFM-fat free mass / TBM total body mass/ FM-fat mass.

Statistical analyses

The normality of the data distribution was confirmed by the Shapiro - Wilk test. The Levine tests were used to verify the homogeneity of the variance of the sample data. A three-way ANOVA for mixed designs was used to test the effects of leg (dominant × nondominant), training (pretest × posttest), and mesocycle (step load 2021/2022 × linear load 2022/2023). An alpha level of <0.05 was considered significant. When a significant main effect or interaction was found, post hoc Bonferroni tests were used to analyze the comparisons. The magnitude of the mean differences was expressed with the standardized effect sizes. The thresholds for the qualitative descriptors of Hedges g were interpreted as ≤0.20 "small", 0.21–0.79 "medium", and >0.80 as 'large. All calculations were carried out using Statistica v.13.3 (StatSoft, Inc., OK, USA).

Results

Sample size analysis

A sensitivity analysis was performed using G*Power software (version 3.1.9.2, Düsseldorf, Germany) to determine the smallest effect size that could be detected with a power of 80% ($1-\beta=0.80$) and a significance level of $\alpha=0.05$ in a three-way repeated-measures ANOVA (within-between interaction). Given a total sample size of 16 participants, the analysis indicated that the study was powered to detect an effect size of at least g = 0.61.

Knee extension

Leg × training × mesocycle interaction. The three-way ANOVA showed a significant leg × training x mesocycle interaction ($F=14.12$; $p=0.002$; $\eta^2p = 0.47$) for the knee extension relative peak torque, however there was no significant leg × training × season interaction ($F=0{,}31$ $p=0.58$, $\eta^2p = 0.02$) for the knee extension relative peak power.

The effect of limb. There was a significant main effect of the leg (dominant and non-dominant leg) ($F=9.13$; $p=0.008$; $\eta^2p = 0.36$) on relative peak torque. The post-hoc test showed significant differences in relative peak torque values between the dominant and non-dominant leg during the step load – season 2021/2022 and 2022/2023, both before and after the training intervention. The dominant leg was characterized by higher values compared to the non-dominant leg. However, there were no significant differences during the linear load – season 2022/2023 ($p>0.05$). Additionally, there was no significant main effect of leg on relative peak power of the dominant and non-dominant leg, before and after the training session.

The effect of training. A significant main effect of the training intervention was found (pre-test and post-test) on both the knee extension relative peak torque ($F=223.13$; $p<0.001$; $\eta^2p = 0.93$) and the knee extension relative peak power ($F=37.1$; $p<0.01$; $\eta^2p = 0.7$). The post-hoc test showed significant differences in relative peak values of torque and relative peak values of power before and after the training intervention, both in the dominant and non-dominant leg during both seasons ($p<0.05$). After the training period, significantly higher values could be noticed. The exception was the lack of difference in relative peak power values before and after the training intervention in the linear load – season 2022/2023 for the non-dominant leg.

The effect of the season. No significant effect was recorded for the mesocycle (step load – season 2021/2022 and linear load – season 2022/2023) for the knee extension relative peak torque ($F=0.011$; $p=0.92$; $\eta^2p > 0.01$) and the knee extension relative peak power values ($F=0.08$, $p=0.78$, $\eta^2p = 0.005$).

Knee flextion

Leg × training × mesocycle interaction. The three-way ANOVA showed a significant leg × training × mesocycle interaction ($F = 17.89$; $p < 0.01$; $\eta^2 p = 0.53$) for knee flexor relative peak torque; however, there was no significant leg × training × season interaction ($F = 0.91$; $p = 0.35$; $\eta^2 p = 0.06$).

The effect of the limb. There was a significant main effect of leg (dominant and non-dominant leg) ($F = 39.04$, $p < 0.01$, $\eta^2 p = 0.71$) on the knee flexor relative peak torque, but not for the knee flexor relative peak power ($F = 1.58$, $p = 0.23$, $\eta^2 p = 0.09$). The post-hoc test showed significant differences in relative peak torque values between the dominant and non-dominant leg during the the step load – season 2021/2022 and linear load 2022/2023, both before and after the training session ($p < 0.05$). The exception was the lack of difference in relative peak torque values between the dominant and non-dominant leg before the training session during the linear load – season 2022/2023.

The effect of training. The significant main effect of the training intervention was found (pre-test and post-test) on both the knee extensor relative peak torque ($F = 101.93$; $p < 0.001$; $\eta^2 p = 0.86$) and knee flexor relative peak power ($F = 55.1$; $p < 0.01$; $\eta^2 p = 0.78$). The post-hoc test showed significant differences in relative peak torque values and relative peak power values before and after the training session, both in the dominant and non-dominant leg during the step load – season 2021/2022 and linear load 2022/2023 ($p < 0.05$). After the training intervention, significantly higher values in relative peak torque and relative peak power were noticed. The exception was the lack of difference in relative peak torque values before and after the training intervention in the linear load 2022/2023 for the non-dominant leg and in relative peak power before and after the training session in the linear load – season 2022/2023 for the dominant leg.

The effect of season. No significant effect was recorded for the season (step load – season 2021/2022 and linear load 2022/2023) for the knee flexor relative peak torque ($F = 0.12$; $p = 0.75$; $\eta^2 p > 0.007$) and the knee flexor relative peak power values ($F = 0.17$; $p = 0.68$; $\eta 2p = 0.001$).

Discussion

General assumptions

The present study demonstrated that both step-load and linear-load periodization models significantly improved knee extensor and knee flexor relative peak torque and power following the training intervention. However, the effectiveness of these periodization models varied depending on the training load progression and limb dominance. For knee extensors, training-induced improvements in relative peak torque were greater in the step-load periodization model than in the linear-load model, particularly for the ND limb. While both periodization models led to increases in knee extensor peak torque and peak power, the linear-load model did not significantly enhance relative peak power in the ND limb. Similarly for knee flexors, both periodization models led to increases in knee flexor peak torque and peak power. However, the linear-load periodization did not produce significant post-training improvements in knee flexor relative peak torque for the ND limb or in the knee flexor relative peak power for the D leg. The overall training effects on knee extensors and knee flexors relative peak torque and power were similar between seasons, indicating that the periodization model, rather than the competitive season, influenced adaptations.

First of all, it should be noted that the period preceding both pre-season mesocycles was identical in terms of resistance training structure (%1RM, TUT, movement tempo, sets, repetitions, rest intervals, and the types and order of exercises, as well as running training. The individual training schedule remained the same in both seasons, with all players performing four resistance training sessions and four running training sessions per week at consistent intervals (Figs. 1 and 2). The only difference between both pre-seasons is the length of the break between competition rounds, 12 weeks in 2021/2022 season and 15 weeks in 2022/2023, the latter due to the World Cup in Qatar (Figs. 1 and 2). In both preparation periods, the primary focus was on inducing neuromuscular adaptations while preparing players for the main preason phase[14]. The load progesion methods were based on a linear or a modified nonlinear (undulating) periodization model (Figs. 3 and 4)[15,16]. Both mesocycles were structured around movement tempo and TUT, which, according to Wilk et al., are integral components of training volume[17]. However, training intensity remained constant, as it was determined using VBT, where in each subsequent microcycle, the velocity was maintained within 1–0.75 m/s, regardless of TUT and movement tempo (Tables 1 and 2)[18]. VBT is a valid method for monitoring resistance training progression, offering real-time feedback on movement velocity, which serves as an indicator of fatigue[18]. By adjusting load based on actual performance rather than pre-determined percentages of 1RM, VBT enables a more individualized approach to resistance training[18]. This method ensures that athletes train within an optimal intensity range, allowing for effective neuromuscular adaptation while minimizing excessive fatigue[18]. In the context of this study, VBT was essential for maintaining consistent training intensity across microcycles, ensuring that changes in movement tempo or TUT did not compromise overall performance output. Monitoring velocity within this study was particularly important, considering that variations in movement tempo across microcycles can influence the athletes' maximal capabilities and directly affect %1RM. This was demonstrated in the study by Wilk et al.[19], which showed that a faster eccentric movement tempo (2/0/X/0) during the bench press exercise resulted in higher power output and greater bar velocity in the concentric phase compared to a slower eccentric tempo (6/0/X/0). Therefore, this study shows that eccentric tempo has a significant effect on the power output and bar velocity. Given these findings, it is possible that periodization strategies incorporating variations in movement tempo and velocity may also influence adaptations related to power generation capacity. Moreover, this research was conducted on a group of professional soccer players who performed only two strength training sessions per microcycle. However, soccer training also includes other components, such as technical, tactical, and conditioning sessions, which significantly contribute to the players' overall training load. Given these additional demands, it is crucial to implement training methods that continuously account for an

Relative Peak Torque (Nm/kg)									
		Dominant limb				Non-dominant limb			
Muscle group	Mesocycle	Pre	Post	Differences %	ES	Pre	Post	Differences %	ES
Extensor	Step Load	2.91 ± 0.44	3.44 ± 0.42	18.4	1.17	2.48 ± 6.67	2.78 ± 0.63	12.2	0.44
	Linear Load	2.89 ± 0.48	3.07 ± 0.47	6.2	0.44	2.78 ± 0.52	2.96 ± 0.52	6.7	0.33
Flexor	Step Load	1.92 ± 0.20	2.68 ± 0.25	39.3	3.2	1.70 ± 0.24	1.88 ± 0.30	10.6	0.63
	Linear Load	2.02 ± 0.32	2.35 ± 0.33	16.4	0.97	1.91 ± 0.28	2.06 ± 0.26	7.9	0.53

Table 3. Relative peak torque during the knee extension and knee flexion before and after the training intervention in the step load in particular seasons. ES – effect size.

Relative Peak Power (W/kg)									
		Dominant limb				Non-dominant limb			
Muscle group	Mesocycle	Pre	Post	Differences %	ES	Pre	Post	Differences %	ES
Extensor	Step Load	2.54 ± 0.69	2.96 ± 0.77	16.2	0.55	2.47 ± 0.74	2.82 ± 0.79	14.3	0.44
	Linear Load	2.74 ± 0.71	2.94 ± 0.75	7.6	0.26	2.63 ± 0.80	2.87 ± 0.78	8.9	0.29
Flexor	Step Load	1.80 ± 0.46	2.39 ± 0.48	32.5	1.2	1.69 ± 0.56	2.22 ± 0.56	31.7	1
	Linear Load	2.06 ± 0.44	2.20 ± 0.45	6.7	0.3	2.00 ± 0.49	2.19 ± 0.45	9.2	0.38

Table 4. Relative peak power during knee extension and knee flexion before and after the training intervention in the step load in particular seasons. ES – effect size.

athlete's current physical condition, such as VBT, which allows for real-time adjustments in training intensity based on the player's readiness and neuromuscular state[2,20].

Linear vs. Step load

It is well estabilished that strength training plays a role in motor performace development and is essential for injury prevention[11,20–22]. However, there is a lack of studies that directly compared the effectiveness of different training periodization models based on TUT, movement tempo, and VBT in the preseason among professional soccer players. The findings of this study clearly indicate that the linear-load mesocycle was less effective in the 2022/2023 season, both for knee extensors and flexors (Tables 3 and 4). Therefore, it is essential to analyze the structural differences between both mesocycles. In this study, linear-load periodization followed the structure of classical linear loading, with the exception that training volume was adjusted using TUT and movement speed. The difference in TUT between the first and last microcycle was 720 s, which is equivalent to the total TUT of a microcycle performed at a movement speed of 3:0:X:0 (Table 2). Another key variable influencing this mesocycle was training intensity, which unlike traditional linear load models,[23,24] remained constant. The external load for three main exercises was selected based on VBT (1–0.75 m/s), corresponding to 50–60% of 1RM. Therefore, this cannot be classified as a classic linear-load model, as it incorporates variable TUT and movement tempo. In our opinion, this strategy, which emphasized TUT accumulation in the early phase of the mesocycle, could have influenced the final results obtained during isokinetic testing. To some extent, this is supported by previous research[24], which suggests that low-intensity, high-volume training at the beginning of the season may lead to accumulated fatigue, directly affecting an athlete's ability to generate strength and power. Another potential factor influecning the observed results in the selection of the VBT zone, as 1–0.75 m/s corresponds to 50–60% of 1RM. According to previous studies[25,26] advanced athletes should exercise with loads of 70–85% of 1RM, indicating that soccer players might have benefited from training in the accelerative strength zone (0.5–0.75 m/s)[27]. However, this raises an important question: should professional soccer players be classified as advanced in strength training? Contrary to previous findings[25,26] López et al.[28] clearly state that the strength and muscular power in soccer players correlate with specific training loads at which peak power is achieved. Their study found that in highly trained soccer players, relative peak power occurs at loads of 45% and 60% of 1 RM during the back squat, which was the primiary resistance exercise at the beginning of the mesocycles in this study (Table 1).

When describing the mesocycle based on the step load 3:1, which was more effective than the linnear load, it is necessary to examine its structure and mechanism. According to its principles, progressive overload is interspersed with deloading microcycles, which is why it is often referred to as the traditional or classic periodization model[4,16,29]. The deloading phase facilitates and enhances both physiological and psychological adaptations, ulimately allowing for supercompensation. In step loading (Fig. 3), instead of a stepwise increase in external load, both TUT and movement tempo increase 2,6,30,31. A similar 3:1 step-load system was used in the study by Drozd et al.[2], which compared the effectiveness of unilateral (UNI) and bilateral (BIL) training. However, a key difference was the number of repetitions per set, which influenced total TUT per set. In their study, TUT per set in the accumulation phase was 50s for BIL and 100s for UNI (50s per limb), whereas in our BIL back squat exercise, TUT was 25s, and in the UNI reverse lunge (high bar) exercise, it was 50s (25s per limb). The shortest TUT per set in our mesocycles was 10s for the back squat and 20s for the reverse lunge (10s

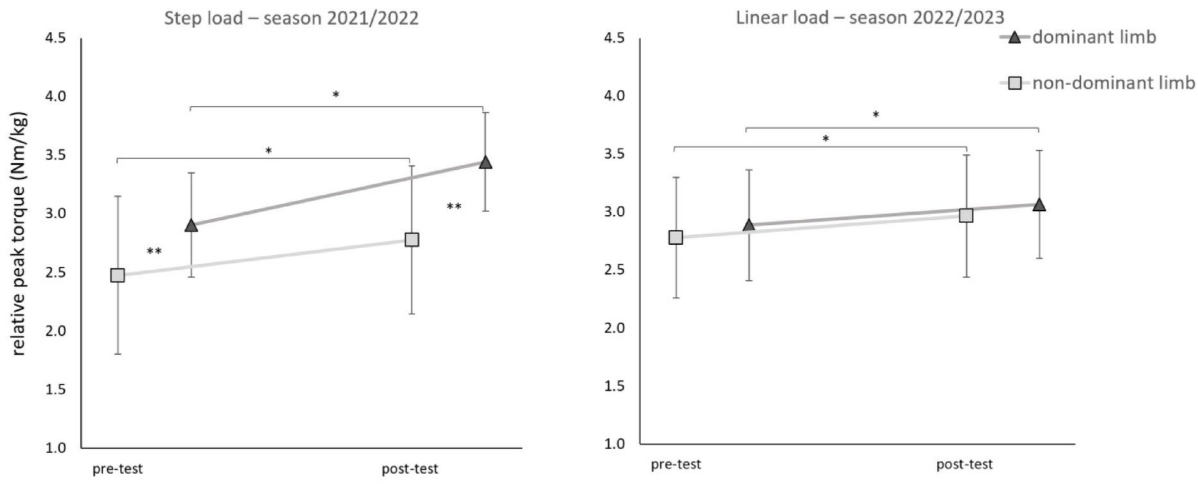

Fig. 5. Mean relative peak torque values of knee extensors for the dominant and non-dominant limbs in the 2021/2022 and 2022/2023 seasons. * $p<0.05$; a significant difference between pre- and post-training within the same limb; ** $p<0.05$; a significant difference between dominant and non-dominant limbs at the same measurement time point.

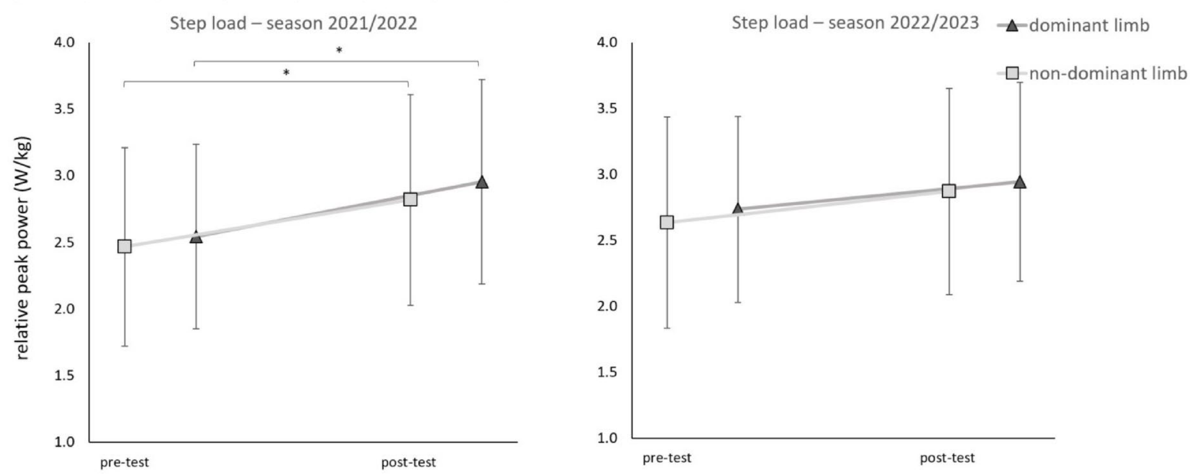

Fig. 6. Mean relative peak power values of knee extensors for dominant and non-dominant limbs in the 2021/2022 and 2022/2023 seasons. * $p<0.05$; a significant difference between pre- and post-training within the same limb.

per limb). This aligns with Trybulski et al.'s[30], who suggested that optimal TUT for strength development ranges from 2 to 20 s. However, it is important to note that this recommendtation applies to individual exercises rather than entire mesocycles. Based on the obtained results, it could be stated that in proffesional soccer players during the preseason, a step load 3:1 model is more effective than a linear-load model for improving relative peak torque and relative peak power of the knee extensors and flexors. However, player adaptation over the two seasons may have contributed to a reduced training effect in the 2022/2023 season compared to 2021/2022. Another crucial factor is the duration of the intervention, which was largely dictated by the length of the preseason. Although the neuromuscular adaptations to resistance training typically become evident after 8–12 weeks[31], some studies have demonstrated significant improvements within just 2–4 weeks, which highlights the practical significance of our findings, particularly for coaches and physiotherapists involved in sports training[2,32,33].

Dominant limb vs. nondominant limb

It is also important to consider both mesocycles in terms of the D and ND limbs (Figs. 5, 6, 7 and 8). This is important because soccer players report having a D and ND limbs, and the movements of each limb are different when kicking the ball. While the hamstrings stabilize the knee and hip in the supporting limb (usually the ND limb), the activity of the hamstrings in the kicking limb is minimized to allow for rapid quadriceps movement, which can lead to imbalance due to stronger hamstrings in the ND limb and stronger quadriceps

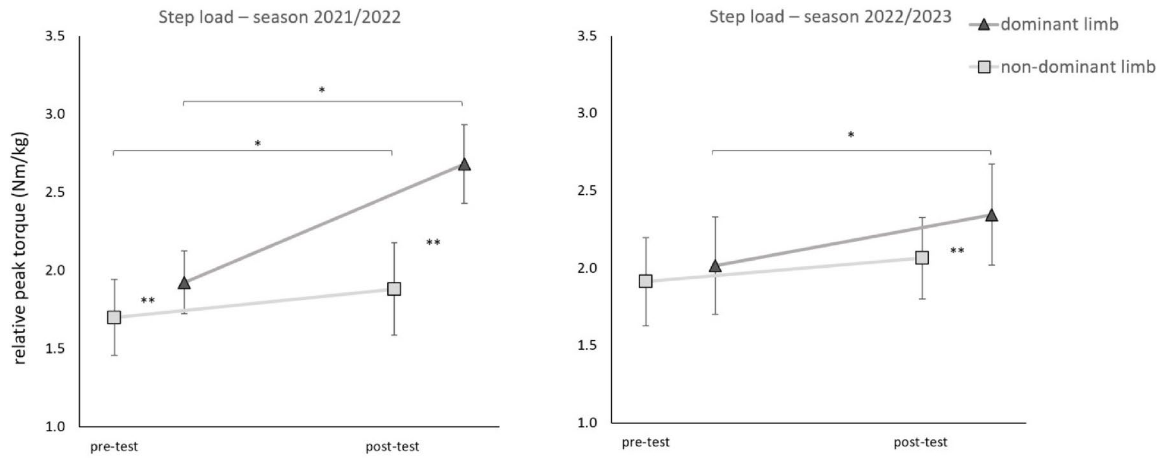

Fig. 7. Mean relative peak torque values of knee flexors for the dominant and non-dominant limbs in the 2021/2022 and 2022/2023 seasons. * $p < 0.05$; a significant difference between pre- and post-training within the same limb; ** $p < 0.05$; a significant difference between dominant and non-dominant limbs at the same measurement time point.

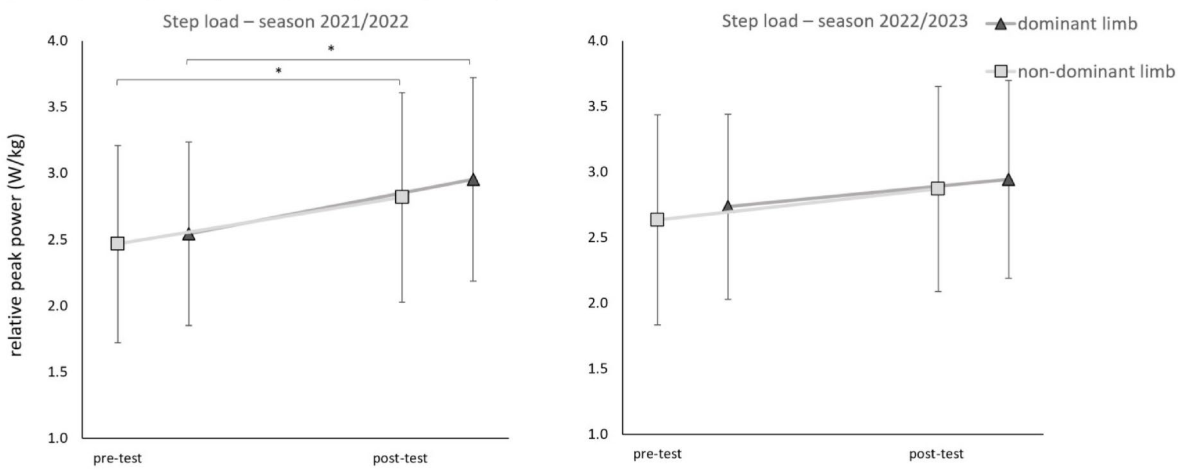

Fig. 8. Mean relative peak power values of knee flexors for the dominant and non-dominant limbs in the 2021/2022 and 2022/2023 seasons. * $p < 0.05$; a significant difference between pre- and post-training within the same limb.

Relative Peak Torque (Nm/kg)							
		Pre-test			Post-test		
Muscle group	Mesocycle	Dominant	Non-dominant	Differences %	Dominant	Non-dominant	Differences %
Extensor	Step Load	2.91 ± 0.44	2.48 ± 6.67	17.3	3.44 ± 0.42	2.78 ± 0.63	23.9
	Linear Load	2.89 ± 0.48	2.78 ± 0.52	3.9	3.07 ± 0.47	2.96 ± 0.52	3.4
Flexor	Step Load	1.92 ± 0.20	1.70 ± 0.24	13.1	2.68 ± 0.25	1.88 ± 0.30	42.4
	Linear Load	2.02 ± 0.32	1.91 ± 0.28	5.3	2.35 ± 0.33	2.06 ± 0.26	13.6

Table 5. The percentage difference in peak torque between the dominant and non-dominant limbs.

in the D limb[34]. Therefore, the evaluation of the effect of both mesocycles on the D and ND limbs showed that the linnear load was less effective in terms of improving relative peak power and relative peak torque (Figs. 5, 6 and 8), but on the other hand it was the only mesocycle that reduced bilateral asymmetry (Tables 5 and 6). Only the % difference in relative peak torque of the 60 knee flexors increased before after from 6.2 to 6.7% (Table 5; Fig. 7). This result can be based on the work of Croisier et al.[35], who reports that any result > 5% can increase

Relative Peak Power (W/kg)							
Muscle group	Mesocycle	Pre-test		Differences %	Post-post		Differences %
		Dominant	Non-dominant		Dominant	Non-dominant	
Extensor	Step Load	2.54 ± 0.69	2.47 ± 0.74	3.1	2.96 ± 0.77	2.78 ± 0.63	4.8
	Linear Load	2.74 ± 0.71	2.63 ± 0.80	3.9	2.94 ± 0.75	2.96 ± 0.52	2.6
Flexor	Step Load	1.80 ± 0.46	1.69 ± 0.56	6.7	2.39 ± 0.48	1.88 ± 0.30	7.3
	Linear Load	2.06 ± 0.44	2.00 ± 0.49	2.9	2.20 ± 0.45	2.06 ± 0.26	0.7

Table 6. The percentage difference in peak power between the dominant and non-dominant limbs.

muscle discomfort and increase the risk of subsequent injuries, leading to maladaptation of bilateral asymmetry caused by the mesocycle. However, if we refer to studies[36] where bilateral asymmetry > 15% is a potential increased risk of injury, the mesocycle based on the linnear load in each variable does not exceed this result. In the context of the validity of the isokinetic test, there are some converging theories because the test itself allows for the assessment of lower limb strength differences, which is an important screening tool for injury risk and a valuable reference point in prescribing rehabilitation programs[37]. However, soccer is a holistic sport and a muscle after a given training plan or after an injury can also regain good muscle strength values, but may still have some elasticity deficit and/or present excessive fibrotic areas, which still expose it to the risk of re-injury. Therefore, torque strength values do not accurately reflect the specificity of muscle work in dynamic situations, as occurs in soccer[38,39]. More surprising are the results obtained in step load 3:1 where a significant increase in bilateral asymmetry of limb D to ND was observed, especially among the relative peak torque 60 knee flexors (Fig. 7) where an increase in asymmetry was observed from 13.1 to 42.4% (Table 5), which is the reason for the significant improvement on the side of the D limb. It was the D limb that achieved the greatest improvement in each of the two mesocycles, and the step load 3:1 mesocycle will cause much greater adaptive changes on the side of the D limb which, as Drozd et al.[2] claim, explosive technical and tactical activities tend to improve more on the dominant side, which partially explains the dependence of maximum force on the recruitment capacity of motor units and the number of nerve impulses reaching the muscles. This, in our opinion, does not further explain such a significant improvement on the side of the D limb taking into account the applied resistance training measures. Only the prolonged eccentric phase in the TUT to some extent explains the greater improvement of knee flexors in both the step and the linnear load. Another factor influencing the increase in muscle asymmetry in the step load periodization may result from the mesocycle structure itself and the accumulation phase that occurs in the 3rd microcycle (Fig. 1; Table 2). This is important because we will take into account the density, volume and intensity of soccer training, without knowing the exact training measures, which, as we have already written, is a certain limitation of this work. It is likely that soccer players have a significantly greater volume measured by the Catapult GPS system resulting from the total distance and intensity of variables such as high-speed running (> 20–25 km/h) and sprinting (> 25 km/h) and a greater number of muscle tensions (acceleration, deceleration) than in the case of linear load accumulation, which occurs in the first microcycle. This may cause the accumulation of neuromuscular fatigue to cause compensation in the correct technical execution of the exercise, also taking into account the set VBT value. It is probable, in our opinion, that this contributes to the occurrence of the phenomenon of bilateral deficit (BLD), considered a precursor of sports injuries[40]. BLD is defined as a phenomenon in which the maximum muscle force of each limb is greater than the maximum muscle force of both limbs performing a given movement pattern. Therefore, an athlete may unconsciously and also in a way invisible to coaches perform BIL, e.g. back squat, in an asymmetric manner, contributing to or deepening musculoskeletal imbalance[41,42]. However, as stated by[43] muscle asymmetry is somewhat inconsistent and its magnitude depends on the movement structure and individual predispositions to perform specific actions[44,45]. Interestingly, one of the studies[46] on muscle asymmetry showed that over 70% of players showed higher peak torque knee extensor values for the ND limb, and 75% of players showed higher peak torque of knee flexor values in the D limb during the isokinetic dynamometry test at (60°/s). The authors argue from their results that the influence of limb D on asymmetry scores was most pronounced in the isokinetic dynamometer test as this likely reflects the obvious mechanical similarities between ball striking and the test protocol.

The limitations of the study

This study has several limitations that should be considered when interpreting the results. While isokinetic strength testing provides valuable insights into neuromuscular adaptations, it does not directly translate to sport-specific performance measures such as sprinting, jumping, or change of direction ability, which are critical in soccer. Moreover, the analysis was limited to the knee extensors and flexors, excluding other key muscle groups that contribute to overall soccer performance, such as the hip and ankle musculature. Fruthermore, the study did not include physiological measurements, such as hormonal, metabolic, or neuromuscular markers (i.e. electromyography assessments), which could offer further insights into the mechanisms underlying observed performance changes. In addition, external training loads from other soccer training sessions were not controlled. While both mesocycles followed structured resistance training protocols, players also participated in technical, tactical, and conditioning sessions, which could have influenced the results. Morevoer, the participants in this study were professional soccer players, which means that the findings should be interpreted with caution when applying them to other athletes. Finally, the sample size was relatively small, which may limit the generalizability of the findings. A larger sample would provide greater statistical power and allow for more robust conclusions.

Conclusions

The findings of this study indicate that both step-load and linear-load periodization models were effective in improving knee extensor and knee flexor relative peak torque and peak power in professional soccer players. However, step-load periodization resulted in more consistent adaptations across limbs, whereas linear-load periodization showed limitations, particularly for the ND limb. Notably, no seasonal effects were observed, suggesting that training responses were independent of the competitive season. Despite the greater effectiveness of step-load periodization in enhancing torque and power, this approach also deepened bilateral asymmetry, primarily due to greater improvements on the D limb. In contrast, linear-load periodization reduced asymmetry but led to smaller overall performance improvements. These findings highlight the trade-off between maximizing strength and power gains versus maintaining lower-limb symmetry, an important consideration for injury prevention and performance optimization. Therefore, step-load periodization may be particularly beneficial when rapid neuromuscular adaptations are needed during the pre-season, but coaches should be careful of its potential to increase asymmetry. Conversely, linear-load periodization could be more suitable for athletes with existing asymmetry issues or those prioritizing movement efficiency over maximal strength gains. It also seems necessary in future work to extend these results based on results from the GPS Catapult device, which will slowly improve our understanding of the discussed periodization problems, especially over such short periods.

Data availability

The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author who organized of the study.

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References

1. Drozd, M. et al. Analysis of the 30-m running speed test results in soccer players in third soccer leagues. *Turk. J. Kinesiol.* **3**, 1–5 (2017).
2. Drozd, M. et al. A comparison of a step load unilateral and bilateral resistance training program on the strength and power of the lower limbs in soccer players. *Appl. Sci.* **14**, 1732 (2024).
3. Rønnestad, B., Nymark, B. & Raastad, T. Effects of In-Season strength maintenance training frequency in professional soccer players. *J. Strength. Cond Res. Natl. Strength. Cond Assoc.* **25**, 2653–2660 (2011).
4. O, B., Carlo, B. & Tudor & *Periodization-6th Edition: Theory and Methodology of Training* (Human Kinetics, 2019).
5. Bortnik, L., Burger, J. & Rhodes, D. The mean and peak physical demands during transitional play and high pressure activities in elite football. *Biol. Sport*. **39**, 1055–1064 (2022).
6. Stone, M. H. et al. Periodization and block periodization in sports: emphasis on Strength-Power Training-A provocative and challenging narrative. *J. Strength. Cond Res.* **35**, 2351–2371 (2021).
7. Zakas, A. Bilateral isokinetic peak torque of quadriceps and hamstring muscles in professional soccer players with dominance on one or both two sides. *J. Sports Med. Phys. Fit.* **46**, 28–35 (2006).
8. Bogdanis, G. C. & Kalapotharakos, V. I. Knee extension strength and Hamstrings-to-Quadriceps imbalances in elite soccer players. *Int. J. Sports Med.* **37**, 119–124 (2016).
9. Ardern, C. L., Taylor, N. F., Feller, J. A. & Webster, K. E. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br. J. Sports Med.* **48**, 1543–1552 (2014).
10. Ekstrand, J., Hägglund, M. & Waldén, M. Epidemiology of muscle injuries in professional football (soccer). *Am. J. Sports Med.* **39**, 1226–1232 (2011).
11. A, D., Ah, N. R. & A, Y. M. Bilateral and unilateral asymmetries of isokinetic strength and flexibility in male young professional soccer players. *J Hum. Kinet* **36**, (2013).
12. HUMAC NORM TESTING & REHABILITATION SYSTEM - PDF Free Download. https://docplayer.net/37846364-Humac-norm-testing-rehabilitation-system.html
13. Almosnino, S., Stevenson, J. M., Bardana, D. D., Diaconescu, E. D. & Dvir, Z. Reproducibility of isokinetic knee eccentric and concentric strength indices in asymptomatic young adults. *Phys. Ther. Sport Off J. Assoc. Chart. Physiother Sports Med.* **13**, 156–162 (2012).
14. Hughes, D. C., Ellefsen, S. & Baar, K. Adaptations to endurance and strength training. *Cold Spring Harb Perspect. Med.* **8**, a029769 (2018).
15. Lorenz, D., Morrison, S., CURRENT CONCEPTS IN PERIODIZATION & OF STRENGTH AND CONDITIONING FOR THE SPORTS PHYSICAL THERAPIST. *Int. J. Sports Phys. Ther.* **10**, 734–747 (2015).
16. Bompa, T. O. & Buzzichelli, C. *Periodization Training for Sports* (Human Kinetics, 2015).
17. Wilk, M. et al. Does tempo of resistance exercise impact training volume?? *J. Hum. Kinet*. **62**, 241–250 (2018).
18. Weakley, J. et al. Velocity-Based training: from theory to application. *Strength. Cond J.* **43**, 31 (2021).
19. Wilk, M., Zajac, A. & Tufano, J. The influence of movement tempo during resistance training on muscular strength and hypertrophy responses: A review. *Sports Med* **51**, (2021).
20. RIBEIRO, J. et al. Methodological characteristics, physiological and physical effects, and future directions for velocity-based training in Soccer: A systematic review. *Balt J. Health Phys. Act* **14**, (2022).
21. Alexe, D. et al. The relationship between functional movement quality and speed, agility, and jump performance in elite female youth football players. *Sports* **12**, 214 (2024).
22. Carvalho, A., Brown, S. & Abade, E. Evaluating injury risk in first and second league professional Portuguese Soccer: muscular strength and asymmetry. *J. Hum. Kinet*. **51**, 19–26 (2016).
23. J, F. & William, K. Steven *Designing Resistance Training Programs, 4E*Human Kinetics,. (2014).
24. Gonelli, P. et al. Effect of linear and undulating training periodization models on the repeated sprint ability and strength of soccer players. *Mot Rev. Educ. Física* **24**, (2018).
25. Wernbom, M., Augustsson, J. & Thomeé, R. The influence of frequency, intensity, volume and mode of strength training on whole muscle Cross-Sectional area in humans. *Sports Med.* **37**, 225–264 (2007).
26. Kraemer, W. J. & Ratamess, N. A. Fundamentals of resistance training: progression and exercise prescription. *Med. Sci. Sports Exerc.* **36**, 674–688 (2004).
27. González-Badillo, J. J. Sánchez-Medina, L. Movement velocity as a measure of loading intensity in resistance training. *Int. J. Sports Med.* **31**, 347–352 (2010).

28. López-Segovia, M., Andrés, P., González-Badillo, J. J. & J. M. & Effect of 4 months of training on aerobic power, strength, and acceleration in two Under-19 soccer teams. *J. Strength. Cond Res.* **24**, 2705 (2010).
29. Bompa, T. O. & Haff, G. *Periodization: Theory and Methodology of Training* (Human Kinetics, 2009).
30. Trybulski, R. et al. Impact of movement tempo distribution on bar velocity during a Multi-Set bench press exercise. *J. Hum. Kinet.* **80**, 277–285 (2021).
31. Folland, J. P. & Williams, A. G. The adaptations to strength training : morphological and neurological contributions to increased strength. *Sports Med. Auckl. NZ.* **37**, 145–168 (2007).
32. Motowidło, J. et al. Effect of step load based on time under tension in hypoxia on the ACL Pre-Operative rehabilitation and hormone levels: A case study. *J. Clin. Med.* **13**, 2792 (2024).
33. Damas, F. et al. Early resistance training-induced increases in muscle cross-sectional area are concomitant with edema-induced muscle swelling. *Eur. J. Appl. Physiol.* **116**, 49–56 (2016).
34. Lutz, F. D. et al. Comparison of the H:Q ratio between the dominant and nondominant legs of soccer players: A Meta-analysis. *Sports Health*. **15**, 486–496 (2022).
35. Croisier, J. L., Ganteaume, S., Binet, J., Genty, M. & Ferret, J. M. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. *Am. J. Sports Med.* **36**, 1469–1475 (2008).
36. Jiang, D. et al. Investigating the impact of inter-limb asymmetry in hamstring strength on jump, sprint, and strength performance in young athletes: comparing the role of gross force. *Front. Physiol.* **14**, 1185397 (2023).
37. Cheung, R. T. H., Smith, A. W. & Wong, D. P. H:q ratios and bilateral leg strength in college field and court sports players. *J. Hum. Kinet*. **33**, 63–71 (2012).
38. Maly, T., Zahálka, F. & Malá, L. Muscular strength and strength asymmetries in elite and sub-elite professional soccer players. *Sport Sci.* **7**, 27–34 (2014).
39. Śliwowski, R. et al. Intra- and inter-limb strength imbalance and asymmetry in Soccer: A comparison of elite senior and junior players. *PLOS ONE* **19**, (2024).
40. Bogdanis, G. et al. Comparison between unilateral and bilateral plyometric training on Single- and Double-Leg jumping performance and strength. *J. Strength. Cond Res.* **33**, 633–640 (2019).
41. Kalata, M. et al. Unilateral and bilateral strength asymmetry among young elite athletes of various sports. *Med. Kaunas Lith.* **56**, 683 (2020).
42. Jones, P. A. & Bampouras, T. M. A comparison of isokinetic and functional methods of assessing bilateral strength imbalance. *J. Strength. Cond Res.* **24**, 1553–1558 (2010).
43. Pardos-Mainer, E. et al. Associations between Inter-Limb asymmetries in jump and change of direction speed tests and physical performance in adolescent female soccer players. *Int. J. Environ. Res. Public. Health*. **18**, 3474 (2021).
44. Bishop, C., Turner, A. & Read, P. Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *J. Sports Sci.* **36**, 1135–1144 (2018).
45. Raya-González, J. et al. Strength, jumping, and change of direction speed asymmetries are not associated with athletic performance in elite academy soccer players. *Front Psychol* **11**, (2020).
46. Nicholson, G. et al. Inter-limb asymmetries and kicking limb preference in english premier league soccer players. *Front Sports Act. Living* **4**, (2022).

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Author contributions
Authors' contributionsConceptualization, MD; methodology, MD and JM; software, MG and JJ; validation, MD; formal analysis, JJ and MS; investigation, MD ; data curation, MD and JM; writing – original draft preparation, MD; writing – review and editing MD; supervision, AZ and JP; project administration, MD. All authors have read and agreed to the published version of the manuscript.

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Declarations

Competing interests
The authors have no conflicts of interest to declare.

Institutional review board statement
This study was conducted in accordance with the Declaration of Helsinki and approved by the Bioethics Committee for Scientific Research at The Academy of Physical Education in Katowice, Poland (No. 3/I/2021), date of approval: 21 January 2021). The experiments complied with the current laws of the country in which they were performer.

Informed consent
Informed consent was obtained from all subjects involved in the study.

Additional information
Correspondence and requests for materials should be addressed to M.D.