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Effect of Concurrent Strength and Endurance Training on Distance Running Performances in Well-Trained Athletes

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Abstract

Athletes competing in distance competitions have used a combination of aerobic and anaerobic training approaches to train and enhance the performance-determining elements. Nevertheless, few studies have reported data related to the effect of concurrent training on well-trained distance (3,000 m – 10,000 m) runners. Because of limited evidence available for this population, this study aimed to investigate the effect of concurrent strength and endurance training on distance running performance. A randomized study was conducted. Thirty-nine distance runners (16.62±0.71 years) were randomly assigned into the endurance training group (ETG; n=13), strength training group (STG; n=13), and concurrent training group (CTG; n=13). The 12 weeks of training in which each group trained 3 times a week. The participants were tested on 1RM squat test, push-up test, VO2 max, and 5-km time trial. Findings showed that STG significantly higher than ETG enhancements on 1RMsquat (p<0.001) and push-up (p<0.001) and STG significantly higher than CTG enhancements on 1RM squat (p<0.001), push up (p=0.045). ETG results were significantly better than those obtained by STG on VO2 max (p=0.002) and 5-km time trial (p=0.004). Finally, the improvements obtained by CTG were significantly higher than those attained by ETG on 1RM squat (p<0.001), push-up (p<0.001); VO2 max (p<0.001) and 5-km time trial (p=0.002). In conclusion, performing 12-week concurrent training program improves performance variables that can be obtained with strength and endurance training in long-distance running. Athletes can acquire strength and endurance adaptations by engaging in concurrent training regimens.

Keywords: *aerobic training, muscle strength, physiological performance, resistance training*

Introduction

Distance running performance is the consequence of a complex interaction of physiological and physical factors and it is dominated by combinations of strength, speed, endurance, flexibility, and coordination (Blagroveet al., 2018). Athletes competing in distance events have improved performance-determining factors using a combination of aerobic and anaerobic training methods (Berryman et al., 2017). Furthermore, due to the nature of the competition schedule or training time available distance running often performs a combination of endurance training and strength training on the same day (Enright et al., 2017). There is growing evidence that concurrent strength and endurance training improves running performance more than endurance training alone, even though the factors that determine distance running performance have historically been established by aerobic running training (Blagrove, Howatson, & Hayes, 2018).

According to a thorough systematic evaluation, concurrent strength and endurance training has a moderately positive impact on middle and long-distance time trials up to 10 km (Blagrove et al., 2018). The effect of concurrent training has been widely investigated by researchers. Some of them provide strong evidence that after concurrent training intervention muscle hypertrophy, strength, and power adaptations

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were mostly attenuated, compared with those after isolated strength training stimuli (Tsitkanou et al., 2017). Conversely, Boullosa et al. (2020), and Ferrari et al. (2021) stated that combining training strength and cardiorespiratory fitness with strength in a training cycle could increase performance more than single-mode training.

In the word of Piacentini et al. (2013), endurance athletes benefit from concurrent strength and endurance training because the rate of force production, one of the key factors of endurance performance, is critical for running. There have been numerous research investigations looking into the function of maximal oxygen consumption (VO2max) in distance running. In heterogeneous groups, research has demonstrated a substantial correlation between VO2max and middle-distance (800 m, r=0.75) and long-distance (marathon, r=0.78) performance (Ingham et al., 2008; Beattie et al., 2017). Another study also showed eight weeks of concurrent strength and endurance training has beneficial effects on musculoskeletal power, maximal oxygen uptake, and the record level of running time (Saud & Nabia, 2016). Significantly, the majority of past studies on concurrent training have concentrated on confirming the compatibility of concurrent strength and endurance training. And research findings are sometimes ambiguous in this area, and it is still unclear how useful strength training is for endurance athletes. Consequently, this study investigated the effects of 12 weeks of concurrent strength and endurance training on the performance of long-distance running. This study expected that concurrent training may have significant effect on long-distance running performance. So, this study examined the effect of strength, endurance, and concurrent training on the performance of long-distance running.

Methods

Study design and participants

A randomized study was conducted. Using random sampling select 39 well-trained distance runners (3,000 m – 10,000 m) from the Tilili athletics center. After being informed of the benefits and potential risks of the investigation, participants were randomized into three groups based on their 5km running time; Endurance training group (ETG) (n=13; 16.7±0.8 years; 57.77±2.29 kg (kilogram); 1.72±0.05 m (meter)), Strength training group (STG) (n=13; 16.62±0.86 years; 56.42±2.01 kg; 1.72±0.05 m) and Concurrent training group (CTG) (n=13; 16.55±0.686 years; 56.96±2.24 kg; 1.717±0.06 m). Participants in the study had an average training background of at least 2 years.

All experimental procedures were ratified by the Bahir Dar University, Sports Academy Research Ethics Committee (No. ERC 01/2022). In addition, all participants in this research had to provide written informed consent.To investigate the effect of concurrent strength and endurance training intervention on strength qualities, physiological indicators, and a 5km time record of long-distance running; the researchers collected quantitative data through appropriate field tests measures such as the Cooper VO2 max test, push-up test, 1RM squat test, and 5km time trial.

Training protocol

Athletes were kept in a training log, which included any physical activity done outside of the training program. All training sessions were coached by an experienced coach. Each strength session lasted approximately sixty minutes. The training program lasted 12 weeks, with study participants attending three non-consecutive sessions per week. The training interventions took place from the beginning of September to the end of November 2022.

Strength training

The training sessions included squat, leg curl, triceps extension, bench press, calf raise, trunk extension, pulldown, hurdle hops, extended bounds, and uphill running performed. There are rests between sets and between exercises. This training program is performed by STG. A more detailed description of the strength training program is presented in Table 1.

Table 1. Training Methodology that Was Used Within STG

Week	Training Parameters							
	Exercises	I (% 1RM)	S (No)	Rep	Di (Km)	Incl (%)	RTS (′)	RTR (′)
1	Squat, Leg Curl, Triceps Extension	60	4	14			2	
2	Squat, Bench Press, Calf Raise	65	4	12			2	
3	Trunk Extension, Leg Curl, Calf Raise	70	5	12			2	
4	Squat, Leg Curl, Pulldown	75	5	10-8			3	
5	Squat, Bench Press, Calf Raise	80	4	8-6			3	
6	Squat, Bench Press, Calf Raise	90	4	8			3	
7	Squat + Hurdle Hops + 2′30″ Running at 100% Of MAS	80	6	6+10			5	
8	Squat + Hurdle Hops + 2′30″ Running	82	6	5+10			5	
9	Squat + Extended Bounds (Cover 50 M Alternating Legs by Doing the Lowest Possible Number of Strides) + 2′15″ Running.	84+105	6	4			5	
10	Squat + Extended Bounds (Cover 50 M Alternating Legs by Doing the Lowest Possible Number of Strides) + 2′ Running	86+110	6	3			5	
11	Uphill Running	115	3	5	0.2	6	10	3
12	Uphill Running	120	2	5	0.2	6	10	3

Notes: 1RM: One-repetition maximum; Di: Distance; Incl: Inclination; Km: Kilometer;MAS:Maximume average speed; No: Number, Rep: Repetitions; RTR:Resting time between reps; RTS: Resting time between sets; S: Sets; STG: strength training group

Endurance training

The main components of endurance training (see table 2) were continuous exercise lasting 45–50 minutes, Fartlek for 40–60 minutes, and reputation training. The amount of time devoted to endurance training and how this time was distributed throughout the training zones were the same across endurance-only training groups and concurrent training groups.

Table 2. Training Methodology that Was Used Within ETG

Week	Training Parameters					
	Exercises	I (b.p.m)	Du (′)	Rep (No)	Di(km)	RT (′)
1	Continuous Training	130–140	45			
2	Continuous Training	140–144	50			
3	Continuous Training	145–150	45			
4	Fartlek Training.	115–160	50			
5	Fartlek Training.	115–160	55			
6	Fartlek Training.	115–160	60			
7	Extensive Interval Training (Long Intervals)	155–160	3	10		2
8	Extensive Interval Training (Long Intervals)	160–165	2	10		2
9	Extensive Interval Training (Long Intervals)	165–170	1	14		2
10	Repetition Training	180	3	5		8
11	Repetition Training	185	2	5		6
12	Competition	100		1	5	

Notes: b.p.m: beat per minute; Di: distance; Du: Duration; ETG: Endurance training group;I: Intensity of training; Km: kilometer; No: Number; Rep: Repetition; RT: Resting Time

Concurrent training

The concurrent training group (CTG) performed both strength and endurance programs on the same day, in which the endurance sessions are performed first and after 8-hour rest followed by the strength session. The training program of CTG included the same strength exercises as STG and ETG.

Assessments

To reduce the impact of extraneous factors and tidal variation on outcome measurements, many control procedures were put in place. The participants were instructed to continue living their regular lives, eating their regular meals, and refraining from using any nutritional supplements during the intervention time. After 12 weeks of training, each participant completed a familiarization before physical and physiological tests. After a 48-hour rest period, the lead researcher gave a thorough explanation of the testing procedures. Then before and after the 12-week training program, some anthropometric and physiological parameters were assessed (pretest and posttest). Before beginning the tests, a warm-up was carried out; running for 10 minutes at 60% of one's theoretical maximum heart rate, followed by five minutes of joint mobility activities which serve as the general warm-up.

The participant's body weight, age, and height were all taken into consideration. A Seca digital column scale, model 769, was used to measure body weight (Hamburg, Germany). 1RM squat test was used to assess lower body maximum strength. Participants were instructed to maintain a naturally upright trunk position throughout the assessment. Both hands were securely gripping the bar, which was also being supported by the shoulders. The performer's legs were parallel to the ground when the test began with their knees bent 90 degrees. The subjects then stood up straight with their legs completely extended. Each subject needed between two and four tries to determine their 1RM. Only completed efforts were recorded. Between each trial, there was a three-minute break.

An other test was push-up test; a standard push-up beginning with the hands and toes on the floor, the body and legs in a straight line, feet spaced slightly apart, and the arms outstretched, shoulder width apart, and at a right angle to the torso. The individual lowers their body while maintaining a straight back and knees to a predefined point, to another object, or until their elbows are at a 90-degree angle, then raises their arms back up to their starting positions. The test continues until tiredness until they can no longer perform them in rhythm, or until they have completed the required number of pushups (Saud & Nabia, 2016).

To determine the VO2 max, Cooper's 12-minute run test was employed. Cooper's 12-minute run test should be applied with the newly calculated norm as a viable approach for accurate, correct, and precise assessment of cardiorespiratory fitness in terms of VO2 max (Bandyopadhyay, 2015). The subjects were run for a total of 12 minutes on a 400-meter circular track. The number of completed laps was counted, and the finish line was marked. By dividing the number of complete laps by 400 and adding the distance (in meters) of the final incomplete loop, one may compute the total distance (in meters) traveled in 12 minutes. The following equation was used to predict the VO2 max and convert the distance in meters to kilometers. VO2 max (ml · kg−1 · min−1) = (22.351 × distance covered in kilometers) − 11.288 (Meredith & Welk, 2010).

The running test of choice was a 5-kilometer time trial. Only dry circumstances and winds below 2 m/s were used during testing (Karsten et al., 2016). A 5-kilometer run on a 400-meter outdoor running track was performed after a 10-minute warm-up at a self-determined pace. Participants were instructed to give it their all during the 5-km time trial. Completion times were noted to the nearest second.

Statistical analysis

Descriptive statistical analysis was made to display means (M) and standard deviation (SD). Levene's test was used to confirm the homogeneity of variances, and the Shapiro-Wilk test was performed to compare the normality of the variables. To confirm the performance differences between groups, a one-way ANOVA test was used. A two-way repeated-measure ANOVA was then conducted to evaluate the training effects on the physical and performance characteristics between groups (ETG vs. STG vs. CTG) and within groups (pre-test vs. post-test). When statistically significant p-values were found, post hoc multiple comparisons with Bonferroni correction were used to identify those differences (group-by-time interaction effect or main effects of time or group). To check the consistency between the pre-test and post-test measures, the interclass correlation coefficient (ICC) was calculated for each of the examined performance factors. Low ICC=0.49, moderate ICC=0.50, high ICC=0.75, and remarkable ICC=0.9 were used to interpret ICC data (Koo & Li, 2016). In addition, Cohen's effect size was used to determine the size of treatment effects within groups (ES). The four categories of ESs: are no significant (0.25), minor (0.25-0.50), moderate (0.50-1.0), and large (>1.0) (Cohen, 2013). The defined level of significance was $p<0.05$. Data were statistically analyzed using the IBM SPSS V.26 computing application (IBM Corp., Armonk, NY, USA).

Results

Thirty-nine individuals completed the study without mentioning any harm they may have suffered as a result of the intervention training session. According to the Shapiro-Wilk test and Levene's test, all variables appeared to have a normal and homogenous distribution. Moreover, the ICC values for all three groups were higher than 0.9 between the pre-test and post-test for all parameters. Results of comparative analysis (one-way ANOVA) among ETG, STG, and CTG at baseline (see Table 3) revealed that there were no statistically significant differences before the start of the training program.

Table 3. Baseline characteristics of participants in each training group

Variables	Group			F	P
	ETG (n=13) M±SD	STG (n=13) M±SD	CTG(n=13) M±SD		
Age (y)	16.54±0.52	16.62± 0.86	16.69±0.85	0.131	0.877
Height (m)	1.72±0.061	1.72±0.05	1.71±.04	0.153	0.859
Weight(kg)	57.76±2.29	56.42±2.00	56.96±2.24	1.249	0.299
1RMSquat (No)	53.00±1.78	53.00±1.78	54.00±1.78	1.368	0.267
1RMPush up (No)	23.77±1.96	23.31±2.097	23.85±1.77	0.290	0.750
Vo2max ($ml.kg^{-1}.min^{-1}$)	68.38±1.23	68.40±1.19	68.37±1.089	0.002	0.998
5km time trial	1010.38±15.21	1010.02±14.90	1009.95±14.73	0.003	0.997

Note: M±SD=mean ± Standard deviation, ETG= Endurance Training group, STG= Strength training group, CTG= Concurrent training group, y= year, m= meter, kg= kilogram, $ml.kg^{-1}.min^{-1}$= milliliters per kilogram per minute, M= Male, F= Female, n= number of participants, No=number; P=statistical significance.

As for the within-subject comparisons, the two-way repeated ANOVA revealed (showed in Table 4), STG significantly improved between the pre-and post-tests in 1RM squat ($p<0.001$; d=8.40), 1RM push-up ($p<0.001$; d=7.26), VO2max (p=0.0185; d=0.19) and 5 km time trial (p=0.001; d=0.14). The effect size of these improvements was small in the case of VO2 max and 5-km time trial, and large for 1RM squats and push-ups. Similarly, ETG significantly improved between

Table 4. Results were obtained by the Three Experimental Groups in the Pre-and Post-Test in all the Variables Assessed

Variable	Group	PT (M± SD)	POT(M±SD)	P-value	Cohen's d
1RMSquat(Kg)	STG	53.00±1.78	69.31±2.09	<0.001	8.40
	ETG	53.00±1.78	59.23±1.96	<0.001	3.33
	CTG	54.00±1.78	64.15±1.2	<0.001	6.69
Push Up (No)	STG	23.31±2.09	38.38±2.06	<0.001	7.26
	ETG	23.77±1.96	28.85±2.04	<0.001	2.32
	CTG	23.85±1.77	34.00±1.78	<0.001	5.72
Vo2Max(mL/kg/min)	STG	68.40±1.19	68.19±1.01	0.0185	0.19
	ETG	68.38±1.24	71.24±0.78	<0.001	2.76
	CTG	68.37±1.08	74.22±1.45	<0.001	4.58
5km Time Trial (sec)	STG	1010.01±14.9	1012.66±13.4	0.011	0.14
	ETG	1010.38±15.2	974.69±9.9	<0.001	2.78
	CTG	1009.9±14.73	936.38±17.2	<0.001	4.53

Notes. 1RM: One-repetition maximum; CTG: Concurrent training group; ETG: Endurance Training group; M±SD: Mean ± Standard deviation; POT: Post-Test; PT: Pre-Test; STG: Strength training group the pre-and post-tests in the following parameters:1RM squat (p<0.001; d=3.33), push-up (p<0.001; d=2.32), VO2 max (p<0.001; d=2.76) and 5-km time trial (p<0.001; d=2.78). The effect size of these improvements was large in the case of all variables. In addition, CTG significantly improved its results between the pre-and the post-tests in the following variables; 1RM squat (p<0.001; d=6.69), push-up (p<0.001; d=5.72), VO2 max (p<0.001; d=4.58) and 5-km time trial (p<0.001; d=4.53). The effect size of these improvements was large in the case of all variables.

Then, the two-way repeated ANOVA (see Table 5) showed that there was a group-by-time interaction effect for 1RM squat, push-up, VO2 max, and 5-km time trial ($F_{(2-36)}$=90.946, p<0.001, $F_{(2-36)}$=543.257, p<0.001, $F_{(2-36)}$ = 138.841, p=0.001 and $F_{(2-36)}$=175.685, p<0.001, respectively). The 1RM squat, 1RM push-up, VO2max, and 5-km time trial all showed a main effect of time ($F_{(1-36)}$=1255.794, p<0.001, $F_{(1-36)}$=6652.971, p<0.001, and $F_{(1-36)}$ =458.374, p<0.001, respectively). The 1RM squat ($F_{(2-36)}$=36.508, p<0.001), push-up ($F_{(2-36)}$=18.345, p<0.001), VO2 max ($F_{(2-36)}$=26.579, p<0.001), and 5-km time trial ($F_{(2-36)}$=26.155, p<0.001) were the last exercises to show a main impact of the group.

Table 5. Between-Subjects Comparisons of all the Variables Assessed

Variable	Main Effect of Time		Main Effect of Group		Group x Time Interaction Effect	
	F (1-36)	P	F (2-36)	P	F (2-36)	P
Body weight	385.714	<0.001*	1.635	0.209	428.464	<0.001*
1RMSquat	1255.79	<0.001*	36.508	<0.001*	90.946	<0.001*
Push up	6652.97	<0.001*	18.345	<0.001*	543.257	<0.001*
Vo2max	364.653	<0.001*	26.579	<0.001*	138.841	<0.001*
5km Time trial	458.374	<0.001*	26.155	<0.001*	175.685	<0.001*

Notes. F: Variation between sample means/variation within the samples; p: Level of statistical significance; VO2max: Maximum oxygen consumption; *p<0.05

Table 6: Bonferroni post hoc comparison

	Group(I)	Group(J)	d= (I-J)	CI 95 (Up	LB)	P-value
1RMSquat	ST	ETG	5.04*	3.55	6.53	0.000
		CTG	2.08*	0.59	3.57	0.004
	CTG	ETG	2.96*	1.47	4.45	0.000
1RMPush up	STG	ETG	4.54*	2.65	6.43	0.000
		CTG	1.92*	0.03	3.81	0.045
	CTG	ETG	2.62*	0.73	4.50	0.004
Vo2max	ST	ETG	-1.52*	-0.48	-2.55	0.002
		CTG	-3.00*	-1.96	-4.03	0.000
	CTG	ETG	1.49*	2.52	-0.45	0.003
5km Time trial	STG	ETG	18.80*	5.54	32.05	0.003
		CTG	38.17*	24.91	51.42	0.000
	CTG	ETG	-19.37*	-32.62	-6.11	0.002

Note: VO2max= Maximum oxygen consumption, CI95 (Up-LB) = 95% Confidence Interval (Upper Bound-Lower Bound), p = Level of statistical significance, * = The mean difference is significant at the 0.05 level, d = Mean Difference, (I-J) =Group(I)-Group(J).

Discussion

Based on the statistics applied; our results confirm: concurrent training improves distance running performance. Finding out whether concurrent training saw the greatest gains in muscle strength after concurrent training compared to endurance training only (CTG) and strength training only (STG) was one of the study's main objectives. After 12 weeks of training, the STG and CTG groups had significant increases in lower-body and upper-body strength as seen by the group's post-training values for the 1RM squat and 1RM push-up tests. Only the marks acquired by endurance training only (ETG) were considerably lower than those attained by STG and CTG in the post-test. STG and CTG both saw an improvement in their scores between the pre-and post-test. Given that strength training and endurance training are combined in the same training sessions, this may mean that adding strength training to endurance training offers extra benefits. In line with this study, Saud and Nabia's (2016) findings showed that concurrent training obtained greater improvements in 1RM squats and push-ups. Similar to this, according to Prieto and Sedlacek (2022), the concurrent training did not experience the interference effect because there were no significant differences between strength training and concurrent training in the post-test results for the 1RM squat. They also improved their marks in the resistance training group and the 1RM squat between the pre-and post-tests.

The current findings additionally demonstrated that maximal strength (i.e., 1RM) increased in STG and CTG while

ETG saw only minor changes as a result of the intervention. Similarly, Sousa et al. (2018) studies conducted with trained distance runners also found gains in maximal strength with concurrent training. The gain in upper body strength for the push-up test in the STG and CTG groups was also significantly different. Results from previous studies by Vikmoen et al. (2017) are consistent with those from the current study. The findings of the current study are in line with those of Vikmoen et al. (2017), and Sousa et al. (2017).The effectiveness of concurrent training to enhance the 1RM squat and push up was confirmed in two instances (Prieto & Sedlacek, 2022).

VO2 max is the most important physiological performance indicator in distance running (Beattie et al., 2014). The trainability of the VO2 max variable could be conditioned by genetic factors (Williams et al., 2017). In this study, the ETG (68.38±1.24→71.24±0.78 ml.kg-1.min-1) and CTG (68.37±1.08→74.22±1.45 ml.kg-1.min-1) obtained significant improvements. It follows that these enhancements are likely training-specific adaptations. Also, the fact that ETG's benefits were not greater than CTG's shows that no interference effect has taken place. These findings are in agreement with studies by Patoz et al. (2021). However, in a systematic review, Blagrove et al. (2018) verified that the implementation of concurrent training programs has no impact on VO2 max. Few studies found significant improvements in VO2 max after the exclusive practice of strength training. In this regard, only three out of the 17 studies analyzed by Ozaki et al. (2013) were used to review the research on the benefits of strength training on boosting VO2 max. Thus, the disparity between studies may exist because there is a genetic predisposition to VO2 max improvement (Williams et al., 2017). They also discovered that increasing VO2 max becomes more challenging the more intense the exercise (Ozaki et al., 2013). In the other study, by Berryman et al. (2019), strength training was added to the sprint interval training intervention, as was a concurrent regimen consisting of a sprint protocol. While VO2 max was considerably improved only in the concurrent group, there were no variations in maximal force between interventions, indicating that both situations improved.

Finally, regarding the 5-km time trial, both ETG (1010.38±15.2→974.69±9.9) and CTG (1009.9±14.73 → 936.38±17.2) improved this variable. This improvement resulted from the training methods specifically designed to enhance the running time of distance running. In reality, a faster race time would be a better indicator of enhanced performance (Sedano et al., 2013). Likewise, the results attained by CTG were significantly better than those achieved by STG and ETG. Theoretically, CTG decreased by a mean of 73.52 seconds. Furthermore, as expected, STG did not significantly improve the 5-km time trial (1010.01±14.9 seconds →1012.66±13.4 seconds). In this occurrence, we believe that the lack of endurance training accounts for the lack of appreciable progress. These results are corroborated by Beattie et al., (2014), which showed that adding a strength training program to an endurance training regimen greatly improved performance during a 5km time trial.

Finally, it is important to discuss the study's strengths and limitations. Regarding the strengths, there are two important features. First, strength training group was added along with concurrent and single-mode endurance training group. This situation helped confirm the changes endurance runners can achieve with strength training and identify whether interfering effects in CTG might be present. Second, equal weekly training sessions were administered to each of the three experimental groups. It should be noted that in numerous prior research, the concurrent group conducted two or three additional strength sessions per week compared to the endurance training group, indicating that a different number of sessions was used.

As for the limitations, First, the sample size was small. Second, if the intervention period had been longer, the three experimental groups may have seen more gains.

Conclusion

In conclusion, concurrent training program that was implemented improved distance running performance significantly. This study demonstrated that adding strength training to a running program significantly improved strength, VO2 max, and 5km record times. Although speculative, the enhanced lower limb strength levels in the CTG group appear to be the primary cause of the trend of improvement, which may have improved elements like stride length.

Practical Applications

The practical implications would relate to: Athletes can acquire strength and endurance adaptations by engaging in concurrent training regimens. To do this, however, a minimum of nine hours between training sessions is required to avoid severe interferences, or 24 hours to more fully ensure that the adaptations won't be attenuated (Baldwin, 2022); The strength training program must be adjusted to the athlete's goals, level of fitness, and prior training experience with regard to the training load and the type of strength that must be produced; Long-term interventions of more than 12 weeks might be used.

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Conflict of interest

The authors declare that there are no conflicts of interest.

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