Impact of strength training in long-distance runners on running performance: a systematic review
Impacto do treinamento de força em corredores de longa distância sobre a performance na corrida: uma revisão sistemática
Impacto del entrenamiento de fuerza en corredores de calle sobre una actuación en la carrera: una revisión sistemática

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Resumo. A corrida de rua é um dos esportes mais praticado em todo mundo, o seu desempenho é influenciado por uma complexa interação entre parâmetros fisiológicos, metodológicos e mecânicos, ambientais e psicológicos. Com isso o objetivo da presente revisão sistemática foi avaliar os impactos do treinamento de força aplicado a corredores de longa distância sobre o tempo de corrida. Foram encontrados 803 artigos nas bases de dados Medline / PubMed Science Direct / Embase / Scielo/ CINAHL/LILACS, após a aplicação dos critérios de exclusão, apenas 5 artigos foram selecionados para a revisão sistemática. Dos estudos selecionados, os anos de publicação eram entre 2014 e 2022, todos publicados em inglês, sendo 2 em revistas com fator de impacto. A amostra total incluiu 166 voluntários, sendo 152 (91,6 %) homens e 14 (8,4 %) mulheres, a média de idade variou de 20 a 39 anos. Os programas de treinamento de força incluíram treinamento pliométrico, Treinamento de força complexo e Treinamento de força. O percentual médio de melhora no tempo da corrida para o grupo intervenção variou de 2,5 a 11,6 % e o percentual de melhora no tempo para o grupo controle variou de 0,07 a 1,3 %. Os grupos de intervenção que utilizaram do programa de treinamento pliométrico, obtiveram a maior média 11,6% e a menor média 1,6% sobre a variação do tempo de prova. Os resultados desta revisão sistemática apoiam que um programa de treinamento de força gera efeitos positivos na performance de corredores de longa distância.
Palavras-chaves: Treinamento, corrida de rua, performance, treinamento de força

Abstract. Street running is one of the most practiced sports in the world, and a complex interaction between physiological, methodological, mechanical, environmental, and psychological parameters influences its performance. Therefore, this systematic review aimed to evaluate the impact of strength training on long-distance runners on running time. 803 articles were found in the Medline / PubMed Science Direct / Embase / Scielo/ CINAHL/LILACS databases. After applying the exclusion criteria, only five articles were selected for the systematic review. Of the selected studies, the years of publication were between 2014 and 2022, all published in English, 2 in journals with an impact factor. The sample included 166 volunteers, 152 (91.6%) men and 14 (8.4%) women; the average age ranged from 20 to 39. Strength training programs included plyometric, complex, and strength training. The average improvement in running time for the intervention group ranged from 2.5 to 11.6%, and the improvement in time for the control group ranged from 0.07 to 1.3%. The intervention groups that used the plyometric training program obtained the highest average of 11.6% and the lowest average of 1.6% regarding the variation in test time—the results of this systematic review support that a strength training program positively affects long-distance runners' performance.
Keywords: Training, road running, performance, strength training

Resumen. El carrera de calle es uno de los deportes más practicados en el mundo, su desempeño está influenciado por una compleja interacción entre parámetros fisiológicos, metodológicos y mecánicos, ambientales y psicológicos. Por lo tanto, el objetivo de esta revisión sistemática fue evaluar los impactos del entrenamiento de fuerza aplicado a corredores de larga distancia sobre el tiempo de carrera. Se encontraron 803 artículos en las bases de datos Medline / PubMed Science Direct / Embase / Scielo/ CINAHL/LILACS, luego de aplicar los criterios de exclusión solo se seleccionaron 5 artículos para la revisión sistemática. De los estudios seleccionados, los años de publicación fueron entre 2014 y 2022, todos publicados en inglés, 2 en revistas con factor de impacto. La muestra total estuvo compuesta por 166 voluntarios, 152 (91,6%) hombres y 14 (8,4%) mujeres, la edad promedio osciló entre 20 y 39 años. Los programas de entrenamiento de fuerza incluyeron entrenamiento pliométrico, entrenamiento de fuerza complejo y entrenamiento de fuerza. El porcentaje promedio de mejora en el tiempo de carrera para el grupo de intervención osciló entre el 2,5 y el 11,6% y el porcentaje de mejora en el tiempo para el grupo de control osciló entre el 0,07 y el 1,3%. Los grupos de intervención que utilizaron el programa de entrenamiento pliométrico obtuvieron el promedio más alto de 11,6% y el promedio más bajo de 1,6% en cuanto a la variación del tiempo de prueba. Los resultados de esta revisión sistemática respaldan que un programa de entrenamiento de fuerza genera efectos positivos en el rendimiento de los corredores de larga distância.
Palabras-clave: Entrenamiento, carrera de calle, rendimento, entrenamiento de fuerza.

Introduction

Street running is one of the most practiced sports worldwide (de Oliveira & Machado, 2007), both at a recreational and competitive level (Martin et al., 2019).

VO$_2$ is the variable that best expresses the functionality of the cardiorespiratory system during physical exercise (Nunes et al., 2019), representing the integration between the respiratory, circulatory, and muscular systems, used as a control, prescription, and performance parameter. running training (Balsalobre-Fernandes et al., 2016).

Associated with this variable, running economy, which is characterized as oxygen consumption at a pre-determined

submaximal speed (Roschel et al., 2015) and aerobic endurance, explain up to 72% of the performance achieved by athletes (Berryman et al., 2018), which together with biomechanical and anthropometric factors, muscle fiber typology, age, and sex, are responsible for the variability of results in running economy (Balsalobre-Fernandes et al., 2016).

Given this scenario, the physiological and metabolic adaptations that occur in response to training have been widely investigated by researchers (Martin et al., 2019).

The interaction between the neural and muscular systems is fundamental for a better-running economy and performance (Saunders et al., 2006; Bonacci et al., 2009). The last decades have provided evidence that the development of the neuromuscular system is essential for the development of muscular strength (Bertuzzi et al., 2013; Roschel et al., 2015), reducing the incidence of injury risk (Abal, Soidán, Giráldez, 2013; Andreu, 2022), increased movement economy (Paavolainen et al., 1999; Roschel et al., 2015) and improved running performance (Ramírez-Campillo et al., 2014; Machado et al., 2019; Filipa et al., 2022).

The improvement in running economy is a consequence of the intervention of muscular strength training (Støren et al., 2008; Bertuzzi et al., 2013; Llanos-Lagos et al., 2024), which has been attributed to the increased coordination of the lower limbs and muscle coactivation, reducing contact time with the ground (Paavolainen et al., 1999).

However, even with a significant amount of evidence supporting the use of muscular strength training to improve running economy, coaches and athletes explore little of its use in general (Karp, 2007; Filipa et al., 2022), in addition to not carrying out an analysis of the performance variable in the time trial race (Bonacci et al., 2009; Balsalobre-Fernandes et al., 2016; Berryman et al., 2018; Llanos-Lagos et al., 2024).

Previous systematic review studies (Balsalobre-Fernandes et al., 2016; Berryman et al., 2018; Llanos-Lagos et al., 2024) address the description of training programs and the impact of these programs on the variables analyzed, such as strength, power, running economy and VO2 max, and from this point a conclusion based on that the improvement of the variables will lead to an improvement in the race, that is, that the total race time will be shorter.

This opens up a gap as to how much improvement in running strength training programs can provide, as well as which model of strength training program generates the most significant amplitude of improvement in running time, questions that have not yet been answered by previous systematic review research.

Based on the previous statements, the objective of the present study was to describe, through a systematic review, muscular strength training programs and their respective impacts on running time in long-distance runners.

An analysis of running training programs (training distribution, volume, and intensity) was carried out, as these variables can influence the results. The hypothesis is that athletes who do muscular strength training associated with running training would have better running performance when compared to athletes who only train running.

Materials and methods

The present systematic review (SR) on muscular strength training in long-distance runners (TFCLD) was prepared following the criteria of the PRISMA methodology (Moher et al., 2015). The protocol was registered with the National Institute for Health Research – International Prospective Register of Systematic Review PROSPERO (n° CRD42023422332). The PICOT method was used to prepare the guiding question. P – Participants (runners); I – intervention (pre-intervention results); C – comparison (post-intervention result); O – outcome (improvement in race time) and T – intervention time (training program equal to or greater than four weeks).

The data search was carried out in the following databases, Medline / PubMed Science Direct / Embase / Scielo/ CINAHL/LILACS, for potentially eligible studies published in English, Spanish, and Portuguese. The following descriptors were used: The terms "resistance training," "running," and "marathon running" were used in the DeCs and MeSh Terms, and the term "Long-distance runners." The following search terms were used: "resistance training" AND "running," "marathon running" AND "Long-distance runners," "resistance training" AND "Long-distance runners." The search was carried out between May 15th and 25th, 2023.

For the eligibility criteria of the articles, the following were included as Inclusion criteria: studies published between January 2010 and April 2023, which investigated the influence of muscular strength training on the performance of long-distance runners in at least one variable (running performance), after the intervention period of the training program. Studies should have a control group or at least one outcome group (for example, another intervention program).

As exclusion criteria, studies with an intervention period of less than four weeks, studies involving animals, course completion works, dissertations, theses, editorials, letters to the editor, case study articles, narrative, systematic and meta-analysis review articles, or articles that did not have a comparative group or control group in the experiment.

Two reviewers (AFM and MRN) selected the studies by searching the databases. The search results were imported into Rayyan software (Qatar Computing Research Institute, Qatar Foundation, Doha) by a third reviewer (FRS), who was responsible for managing the program and ensuring an independent review by the two reviewers.

The reviewers (AFM and MRN) independently assessed the methodological quality of the selected studies using the Jadad score (Jadad, 1996) and the risk of bias (RoB-2) using the Cochrane tool (Whiting et al., 2016). The two reviewers discussed disagreements between the reviewers until a

consensus was reached. When necessary, a fourth reviewer (JSN) was requested to reach a consensus or arbitration agreement between the reviewers.

The Jadad score and the final score vary from 0 to 5 points. Scores equal to or less than two are considered low quality, and scores similar to or greater than three are considered high quality (Jadad, 1996).

The Risk of Bias Analysis Tool (RoB-2) allows investigators to assign a "high," "low," or "unclear" risk quality score based on seven factors that may bias the effect of the bias program. Intervention is either overestimated or underestimated in individual studies (Whiting et al., 2016).

Results

After applying the eligibility criteria, five articles were included in the present systematic review (Figure 1).

Among the studies selected for the systematic review, in 5 of them, it was identified that the years of publication were between 2014 and 2022, all published in English, 2 of them in journals with an impact factor, and three publications (Li et al., 2019, Machado et al., 2019, Filipa et al., 2022), in a journal without impact factor (Table 1)
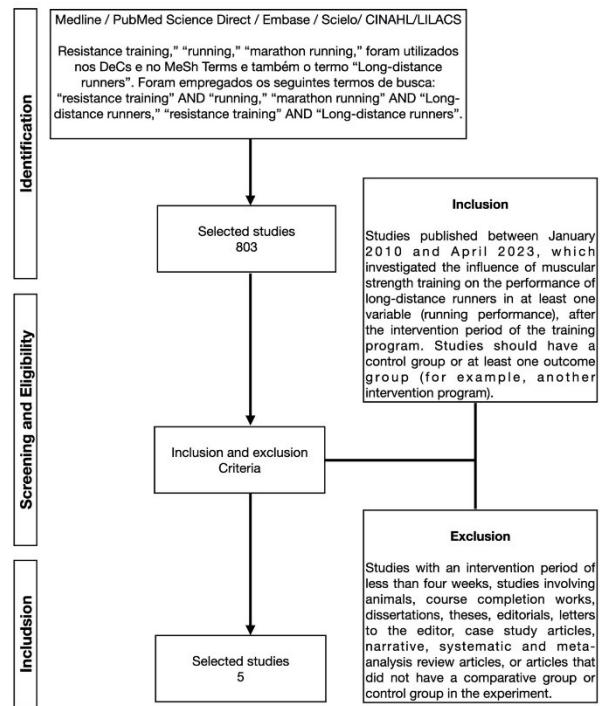

Figure 1. Phases of the methodology for selecting articles included in the systematic review.

Table 1.
General characteristics of the selected studies

Authors	Language	Journal	IF
Ramírez-Campillo et al., 2014	English	*Journal of Strength and Conditioning Research*	4,415
Damasceno et al., 2015	English	*Eur J App Physiol*	3,346
Li et al., 2019	English	*PeerJ*	-
Machado et al., 2019	English	*Journal of Physical Education and Sport*	-
Filipa et al., 2022	English	*Scand J Med Sct Sports*	-

Table 2 and Figure 2 show the methodological quality using the Jadad scale and the RoB-2 assessment, respectively. The average score obtained on the Jadad quality scale (table 2) was 4.2 ±0.4 points for the five studies considered
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high quality. Regarding the double blinding item, the evaluation was not carried out due to the studies being about exercises; therefore, there was no blinding of the volunteers

Table 2.
The methodological quality of the studies according to the Jadad scale.

Study	Was the study described as randomized?	Was There a Description of Randomization?	Were there comparisons and results?	Was there a description of the comparisons and results?	Was there a description of withdrawals and dropouts?	Total
Ramírez-Campillo et al., 2014	1	1	1	1	0	4
Damasceno et al., 2015	1	1	1	1	1	5
Li et al., 2019	1	0	1	1	1	4
Machado et al., 2019	1	0	1	1	1	4
Filipa et al., 2022	1	0	1	1	1	4

The studies selected in this systematic review totaled 166 participants (table 3). Among the participants, 152 (91.6%) were men and 14 (8.4%) women. The average age ranged from 20 (Li et al., 2019) to 39 (Machado et al., 2019).

The minimum intervention time observed in the selected studies was six weeks (Ramírez-Campillo et al., 2014), and the maximum was eight weeks (Damasceno et al., 2015; Li et al., 2019; Machado et al., 2019). The weekly training frequency proposed by the selected studies (table 3) was once a week (Filipa et al., 2022), twice a week

(Campillo et al., 2014; Machado et al., 2019), and three times a week (Damasceno et al., 2015; Li et al., 2019).

The training programs (table 3) used by the researchers addressed training methods characterized as Plyometric training (Ramírez-Campillo et al., 2014; Machado et al., 2019; Filipa et al., 2022), Muscle strength training (Damasceno et al., 2015) and complex strength training and strength training (Li et al., 2019).
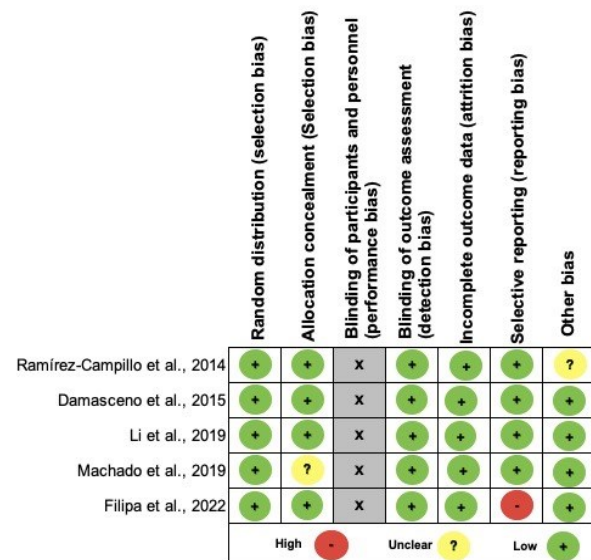

Figure 2. Cochrane risk of bias for individual studies (Roob-2 evaluation). Included studies falling under low risk (green), unclear risk (yellow), and high risk (red) are shown for each of the seven.

Table 3.
General characteristics of the studies

Reference	Sample	Groups - Training program	Results	Conclusion
Ramírez-Campillo et al., 2014	n=36 Mean age 22 years Group TG (n=18) Male (n=10) Female (n=8) Group CG (n=18) Male (n=12) Female (n=6)	Group Training (TG) – 6 weeks – Twice a week plyometric training plus a session of running training weekly volume of 64.7 km. Program - Twice a week, plyometric training sessions last 30 minutes, with a minimum break of 40 hours between plyometric sessions. Warm-up (5 min submaximal running, 20 submaximal vertical jumps, and ten submaximal longitudinal jumps), the central part of the session consisted of 60 drop jumps, 2 x 10 jumps (20 cm), 2 x 10 jumps (40 cm) and 2 x 10 jumps (60 cm). Running training, athletes were instructed to maintain their weekly running training routine. Group Control (CG) – 6 weeks –sessions of running training weekly volume of 70 km. Program - Running training: athletes were instructed to maintain their weekly running training routine.	There were no significant differences between men and women in the percentage change in any test variables before and after training. Significant reduction in 2.4 km race times ($p < 0.01$) and CMJA explosive power jumping performance ($p < 0.001$) in the TG group between the pre and post-intervention moments. There was also a significant difference in the 2.4 km race time ($p < 0.05$) and the CMJA explosive power jump performance ($p < 0.01$) compared to the group CG.	Volunteers achieved significant adaptations with short-duration, low-volume, moderate-frequency plyometric training. The results showed that explosive strength and running endurance training can be performed in the same training session, which can facilitate incorporating this method into the training program schedule.
Damasceno et al., 2015	n=18 Male (n=18) Group STG (n=9) Mean age 34 years Group CG (n=9) Mean age 32 years	Group Resistance Training (STG) – 8 weeks – Twice a week, a resistance and running training session. Program - Exercises (half squat, leg press, plantar flexion, and knee extension) 3 sets of 8 – 10RM for the first two weeks, three sets of 6-8RM (weeks 3 and 4), three sets of 4-6RM (weeks 5 and 6) and two sets of 3-5RM on the last weeks. The remaining interval between sets was 3 minutes. Group Control (CG) – 8 weeks - Running training. Program - Athletes were instructed to maintain their weekly running training routine.	No significant differences ($p > 0.05$) were observed between pre and post-intervention for both groups in the variables: fat percentage, body mass, and volume of weekly running training. There were also no significant differences ($p > 0.05$) between the groups (STG and CG) for the variables VO2 max and RE. A significant difference ($p < 0.05$) was observed between the groups for peak treadmill speed (PTS) and 1RM, in which the TSG group showed a more significant percentage variation concerning the CG. In the 10K time trial race, after the training period, the STG improved its execution time by 2.5%, a value significantly higher than that found in the CG ($p < 0.05$). However, no differences ($p > 0.05$) were observed in RPE before and after training for both groups.	The results show that eight weeks of strength training were enough to optimize the neuromuscular responses of runners in a 10km race. The findings suggest that neuromuscular characteristics may be an important determinant of exercise intensity during the intermediate and final phases of the 10 km race. Furthermore, the present study observed that strength gain after a training program can reduce peripheral fatigue in long-distance athletes during the final stages of a race, resulting in better performance.
Li et al.,	n= 28	Group Complex Training (CT) – 8 weeks – Three times a week,	No differences ($p > 0.05$) were found	The data suggests that

2019	Male (28) Group CT (n=10) Mean age 20 years Group HRT (n=9) Mean age 21 years Group CON (n=9) Mean age 20 years	there is a session of complex training plus endurance training, five times. Program - Exercises (back squat, Bulgarian squat, Romanian deadlifts) 3 sets of 5repetition 80-85%1RM; Drop jump (40 cm), three sets of 6 jumps; Single leg hop (body weight), three sets of six repetitions and Double leg hurdle hop (50 cm), and sets six repetitions, all exercise with 4 minutes of recovery. Group Heavy Resistance Training (HRT) – 8 weeks – Three times a week, there is a session of heavy strength training plus endurance training, five times. Program - Exercises (back squat, Bulgarian squat, Romanian deadlifts) 5 sets of 5 repetitions 80-85%1RM, all exercises with 3 minutes of recovery. Group Control (CON) – 8 weeks – Three times a week, there is a session of strength-endurance training plus endurance training, five times. Program - Exercises (back squat, Bulgarian squat, Romanian deadlifts) 5 sets of 20 repetitions 40 %1RM, all exercises with 1 minute of recovery.	between the CT, HRT, and CON groups during the pre-test in any variable analyzed in the experiment. There was also no difference ($p > 0.05$) in VO2max between the groups after the intervention. The results showed a significant difference ($p < 0.05$) for 1RM and RE (12 km/h) for the three groups after the intervention period. For RE (14 km/h), a significant difference was observed ($p < 0.05$) in the CT and HRT groups, and for RE (16 km/h), a difference ($p < 0.05$) was observed only in the CT group. Regarding performance in the 5 km run, only the CT (-2.80%) and HRT (-2.06%) groups showed significant differences ($p < 0.05$) between the pre-and post-intervention moments.	an 8-week intervention program with CT or HRT combined with endurance training is superior to resistance training combined with endurance training. The data shows a significant increase in 1RM strength, RE (14 and 16 km/h), and 5 km running performance for the TC and HRT groups compared to the CON group.
Machado et al., 2019	n= 24 Male (24) Group PSG (n=8) Mean age 38 years Group PDG (n=8) Mean age 39 years Group CG (n=8) Mean age 35 years	Group Squat Jump (PSG) – 8 weeks – Twice a week, a session of plyometric training with squat jump plus running training (group CG), tree time. Program - Squat jump from a 45 cm box and six sets of 30 seconds (all out), followed by 30 seconds of recovery. Group Drop Jump (PDG) – 8 weeks – Twice a week, a session of plyometric training with drop jumps plus running training (group CG), tree time. Program - Drop jump from a 45 cm box and six sets of 30 seconds (all out), followed by 30 seconds of recovery. Group Control (CG) – 8 weeks – Tree time session of running training. Program - First session, 5 km distance and maximum speed; Second session, 8 km distance and speed of 85% of the pace load obtained in the first session; Third session, 12 km distance and speed of 75% of the pace load obtained in the first session.	The results show that the PSG and PDG groups presented a significantly different time result in the 5 km race ($p < 0.05$) compared to the CG group. However, the groups (PSG and PDG) did not show a significant difference between them; however, the average evolution values between them were numerically substantial. This means that PDG was the most efficient in performance compared to PSG, which is confirmed by the effect size.	From the results of the present study, the protocol with the drop jump movement was the most efficient for developing performance, specifically for street runners. However, the squat jump protocol was also statically effective, and it is recommended that future studies investigate the processes by which the drop jump was significantly more significant than the squat jump for running performance.
Filipa et al., 2022	n= 60 Male (60) Group PYR (n=15) Mean age 35 years Group PYR + PLY (n=15) Mean age 34 years Group POL (n=15) Mean age 34 years Group POL + PLY (n=15) Mean age 34 years	Group Pyramidal (PYR) – 7 weeks - Five weekly running sessions. Program - The endurance training program lasted between 50 and 70 minutes and distributed training throughout the week at 77% (Z1), 17% (Z2), and 6% (Z3). Group Pyramidal + Plyometric (PYR + PLY) – 7 weeks – Once a week, on the day there was no running training. Program - In addition to endurance training, plyometric training was performed. The protocol consisted of 60 Drop Jumps per session (2 sets of 10 jumps from a 20 cm box, two sets of 10 jumps from a 40 cm box, and two sets of 10 from a 60 cm box). Group Polarized (POL) – 7 weeks - Five weekly running sessions. Program - The endurance training program lasted between 50 and 70 minutes and consisted of distributing training throughout the week at 80% (Z1), 6% (Z2), and 14% (Z3). Group Polarized + Plyometric (POL + PLY) – 7 weeks - Once a week, on the day there was no running training. Program - In addition to endurance training, plyometric training was performed. The protocol consisted of 60 Drop Jumps per session (2 sets of 10 jumps from a 20 cm box, two sets of 10 jumps from a 40 cm box, and two sets of 10 from a 60 cm box).	The authors observed a significant difference ($p < 0.05$) between the pre and post-intervention periods within the group, but no significant difference was observed ($p > 0.05$) between the groups. The effect size (D - Cohen) showed a small interaction for the PYR (0.29) and POL (0.21) groups and a moderate interaction for the PYR+PLY (0.56) and PLO + PLY groups (0.66).	The results of the present study allow us to conclude that the improvement in performance in the 5 km was independent of the TID adopted in the groups. The results were more expressive in the groups with the addition of the plyometric protocol. The authors suggest that future studies on runners with different levels (higher and lower) of the present study would be exciting and offer application in other training methods such as cycling.

Table 3 – RE: Running economy; CMJA: Countermovement jump with arms; RPE: Rate of perceived exertion; TID: Training intensity distributions; Z1, zone 1 (i.e., training volume below the first ventilatory threshold); Z2, zone 2 (training volume between the first and second ventilatory thresholds); Z3, zone 3 (training volume above the second ventilatory threshold);

In Table 4, the performance index (%) was observed after the intervention period for each group in the selected studies. In this variable, it is observed that the performance rates of the groups in which the intervention protocols were applied varied between 1.6% (Filipa et al., 2022) and 11.6% (Machado et al., 2019).

Table 4.
Reduction of time after the intervention period

Study	Group	Δ (%)	D
Campillo et al., 2014	TG	3.9	2.4
	CG	1.3	
Damasceno et al., 2015	STG	2.5	10
	CG	0.7	
Li et al., 2019	CT	2.8	5
	HRT	2.09	
	CON	0.07	
Machado et al., 2019	PSG	9.4	5
	PDG	11.6	
	CG	0.3	
Filipa et al., 2022	PYR	0.9	5
	PYR+PLY	1.6	
	POL	0.8	
	POL+PLY	1.8	

Table 4 - Δ (%), variation in the percentage of distance referring to the pre-and post-intervention period; D, distance covered in km in the time trial test. Intervention groups: TG, STG, CT, HRT, PSG, PDG, PYR + PLY, POL + PLY; Control groups: CG, CON, PYR, POL.

Discussion

The objective of the present study was to describe, through a systematic review, strength training programs and their respective impacts on running time in long-distance runners. Even with a few studies that met the selection criteria for this review, the findings suggest that a muscular strength training program lasting at least six weeks is sufficient to generate benefits in running time in long-distance runners.

The results presented here corroborate the findings in previous systematic reviews (Bonacci et al., 2009; Balsalobre-Fernandes et al., 2016). In the review proposed by Bonacci et al. (2009), seven articles published between 1997 and 2008 were analyzed. In the review submitted by Balsalobre-Fernandez et al. (2016), the authors selected five published articles between 1999 and 2013.

The minimum duration of the strength training program analyzed in the systematic review proposed by Bonacci et al. (2009) was six weeks, and the maximum was 14 weeks, with a minimum frequency of muscular strength training twice a week. The results showed that of the seven articles analyzed, 5 showed significant improvements in increasing muscle strength, and all seven articles showed substantial improvements in running economy (Bonacci et al., 2009).

In the systematic review and meta-analysis proposed by Balsalobre-Fernandez et al. (2016), the minimum number of intervention periods was eight weeks, and the maximum was 12 weeks, with a minimum training frequency of 2 times a week. The authors compared the difference in the average pre- and post-intervention moment between the experimental and control groups of the articles analyzed and observed that in the five articles analyzed, the groups

that trained strength (practical) associated with running training had significant improvements when compared to the control group that just ran.

Recently, in the systematic review and meta-analysis published by Llanos-Lagos et al. (2024), the authors included 31 articles in their study that were published between 2002 and 2019. The study compared the effects of different strength training programs applied to medium and long-distance runners on running economy.

Unlike the revisions proposed by Bonacci et al. (2009), Balsalobre-Fernandez et al. (2016), and Llanos-Lagos et al. (2024), this systematic review only analyzed the variables related to running performance.

Running performance is influenced by physiological, biomechanical, psychological, and environmental factors (Filipa et al., 2022). The systematic review study by Balsalobre-Fernandez et al. (2016) suggests that muscular strength training significantly improves the movement economy of runners and, consequently, better running performance.

Muscle strength training provides better coordination of the lower limbs and muscle coactivation (Balsalobre-Fernandez, Tejero-González & Campo-Vencio, 2015; Machado et al., 2019; Filipa et al., 2022). Neuromuscular adaptations, including increased strength, are important indicators of improving the athlete's physical condition. In the systematic review study proposed by Berryman et al. (2018), researchers showed that strength training positively impacted performance in long-distance running athletes.

Among the studies analyzed in this systematic review, Ramírez-Campillo et al. (2014) observed significant improvements ($p < 0.05$) in the running time of the intervention group (-3.9%) when compared to the control group (-1.3 %). This study was the only one included in the present systematic review in which the sample (n = 22) was composed of men (n = 22) and women (n = 14).

This study also showed a more significant amplitude variation in the running performance of the intervention group, with an amplitude of -9.1 to -1.1%. Such amplitude variation in the study can be interpreted as a function of the sample comprising both genders and the distance used in the performance test (2.4 km). However, the data available in the study do not allow us to confirm or deny this hypothesis.

The strength training program proposed by Ramírez-Campillo et al. (2014) offers a strength training program based on plyometric training consisting of 60 jumps (drop jump) divided into 20 jumps with a 20 cm drop, 20 jumps with a drop of 40 cm, and another 20 jumps with a drop of 60 cm, the same training program that was later used by Filipa et al., 2022 in their study.

However, the results obtained by Filipa et al. (2022) are inferior to those obtained by Campillo et al. (2014). The intervention groups proposed by Filipa et al. (2022), PYR+PLY and POL+PLY, get an average reduction in a race time of -1.6% and -1.8%, respectively, values lower than that obtained by Ramírez-Campillo et al. (2014),

which was -3.9%.

One hypothesis that can explain the difference in the average percentage of time decrease between studies is the weekly frequency and total volume of jumps. Campillo et al. (2014) propose twice a week, and Filipa et al. (2022) propose once a week.

Another hypothesis that can explain such a difference between the results of the studies by Ramírez-Campillo et al. (2014) and Filipa et al. (2022) would be the distance in the performance test, in which Filipa et al. (2022) used a distance of 5km.

However, the study proposed by Machado et al. (2019) also used the 5 km distance as a performance test and jumping program, but with a frequency of 2x a week for eight weeks and obtained significantly higher results in the percentage of improvement, when compared to all studies present in this systematic review.

Machado et al. (2019) used a training program based on two types of jumps (squat jump and drop jump), which are prescribed based on an interval training proposal with 30 seconds of "all out" stimuli followed by 30 seconds of recovery, with six sets being performed for each of the programs proposed in the study.

The height of the bench for both types of jumps was 45 cm; the total number of jumps was not counted. Therefore, we cannot say that the number was higher or lower than the studies proposed by Ramírez-Campillo et al. (2014) and Filipa et al. (2022).

However, the study by Machado et al. (2019) is the only one that describes the intensity control of specific training (running) during the intervention program and how the intensity adjustment is carried out based on speed during the training period that researchers call pace load.

Based on studies by Casado et al. (2020), Boullosa et al. (2020), and Casado et al. (2023), it is believed that the combination of adjusting the running training load frequently based on speed, associated with the strength training program may have been responsible for the results of the study proposed by Machado et al., (2019) being significantly superior when compared to other studies analyzed in the present systematic review.

Filipa et al. (2022) propose intensity control from training zones (Z1-Z2-Z3) based on heart rate associated with the percentage of total training time but does not report how and if it was carried out adjustments to the reference resting heart rate measurement to recalculate training zones, which may have been a limiting performance factor.

Another point that may have interfered with the results is the control of training intensity based on heart rate (physiological training load). This strategy leads the individual to adjust running speed throughout the training session, as, as the session prolongs, it is normal for mechanical capacity to be reduced depending on the level of conditioning and depletion of energy substrates (Boullosa et al ., 2020), so to sustain the prescribed intensity it is necessary to reduce the running speed.

On the other hand, controlling training intensity based on speed (mechanical training load) requires the athlete to maintain the prescribed speed, even with the onset of fatigue and depletion of substrates, thus generating more significant stress. In the body, compared to intensity control based on heart rate (Casado et al., 2020).

In the study proposed by Li et al. (2019), researchers observed similar decreases in 5km running time between the groups that applied for the intervention program, complex training, and resistance training (-2.8 to -2.09), respectively. The results were significantly ($p < 0.05$) higher when compared to the control group (- 0.07).

The control of training intensity proposed in the experiment by Li et al. (2019) was also based on the percentage of maximum heart rate. However, prescriptions were used within maximum heart rate ranges, from 75 to 85% HRmax for longer training sessions and 90 to 95% HRmax for shorter training sessions.

Li et al. (2019), in addition to proposing intensity ranges based on HRmax with an amplitude of 10%, also offered ranges in the volume of longer training sessions, which varied between 15 and 20 Km, with a high variation in both intensity control (HRmax) as well as the volume (Km) of the training session.

In their study, Li et al. (2019) do not report how the intensity (%HR max) and volume (Km) of the training session are selected, which suggests that the athlete himself makes the choice.

The lack of information on the prescription of intensity and volume compromises the analysis of the work in more detail in this systematic review since the prescription of these two training variables can lead to different forms of manipulation, which could lead to different results at the end of the training program (Bullosa et al., 2020).

Damasceno et al. (2015), in their study, report an improvement in time of -2.5% in the group that used the proposed strength training program when comparing the pre- and post-intervention period.

His strength training program was the only one in the present systematic review that used periodization during the intervention. Every two weeks of training, the program's number of sets and repetitions change (Table 3), and the 10km distance is used to test your running performance.

Regarding the prescription of specific training (running), the athletes only performed low-intensity training (50 to 70% VO2 max) during the intervention period and were instructed to maintain the volume of running training they had already performed before the intervention period.

The lack of details on the distribution of running training more precisely in the study by Damasceno et al. (2015), as in the studies by Filipa et al., 2022, and Li et al., 2019, limits the analysis of studies in the present systematic review.

Therefore, some considerations must be mentioned. Of the five studies selected for this systematic review, we can divide them into three levels of control of running training intensity, namely: level 1, with precise control and detailed description described in the study (Machado et al.,2019);

level 2, with a lower precision control described in the study (Li et al., 2019; Filipa et al., 2022) and level 3 without a control described in the experiment (Ramírez-Campillo et al., 2014; Damasceno et al., 2015).

This systematic review shows us that the strength training program (plyometric, resistance, and complex training) combined with running training improves long-distance running performance, regardless of the runner's conditioning level.

Training programs with a weekly frequency of 1 time, an intervention period of 7 weeks, a training frequency of 2 times, and an intervention period of 6 weeks or more effectively reduced running time.

Practical applications

Based on the data presented, it is recommended to include muscle strength training (resistance training, plyometric training, or complex training) in athletes' training programs at the same time as specific training (running training) to optimize the transfer of the positive effects of the strength training program (coordination of the lower limbs and reduction of contact time with the ground), which will lead to greater running economy and, consequently, better performance in the total time of the race.

It is recommended that the training program be carried out at least twice a week and for a minimum period of 6 weeks. However, as shown in the present systematic review, it is possible to obtain benefits in running performance with just 1 training session per week of strength (plyometric training), as proposed in the study by Filipe et al. (2022).

It is also recommended that the muscular strength training program has a distribution (periodization) within the training program that is aligned with the specific training program (running training), as proposed by Machado et al. (2019), intending to optimize athletes' performance without generating orthopedic overload.

Final considerations

The present study aimed to describe, through a systematic review of the available literature, strength training programs and their respective impacts on running time in long-distance runners. The results of this systematic review support that a strength training program positively affects long-distance runners' performance.

However, future research should investigate the effects of different training distribution strategies based on a more detailed description of specific running training combined with strength training programs applied to long-distance running athletes to better understand the process under the different muscular strength training approaches.

As a suggestion, traditional, plyometric, and combined strength training programs could be applied to runners who train 3, 4, and 5 times a week with different types of train-

ing distribution strategies (pyramidal and polarized) for different training periods (6, 8, 12 and 16 weeks).

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