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STRENGTH TRAINING METHODS IN MIDDLE-DISTANCE ATHLETES: A SYSTEMATIC REVIEW

MÉTODOS DE ENTRENAMIENTO DE FUERZA EN ATLETAS DE MEDIO FONDO. UNA REVISIÓN SISTEMÁTICA

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ABSTRACT

The aim of this systematic review has been to compare different strength training methods to improve performance in events between 800 and 5000 m in athletics, events characterized by high requirements of aerobic capacity, maximal strength, and power. The Pubmed database was used to search for original articles about strength training in middle distance runners. For this purpose, different combinations of some terms such as "middle distance," "running performance," "VO2max," "running economy," "resistance training," "strength training," "concurrent training," and "plyometric training" were introduced. Articles whose interventions were evaluated with time trials longer than 5 km were excluded. Initially, 298 articles were collected, of which 9 were selected according to the inclusion and exclusion criteria. After an intervention period lasting 6 to 12 weeks, improvements in physiological and neuromuscular parameters were observed in all but one of the articles. The studies that obtained the greatest improvements performed strength training with loads of 70% RM or higher. In addition, this strength training was combined with plyometric exercises performed without additional weight or by adding 30% of body weight. In conclusion, combining strength training at an intensity of 70% RM or higher at 4-10 repetitions with plyometric training appears to be the most effective method for optimizing performance in middle-distance running

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Palabras clave:
corredores, resistencia, rendimiento, economía de carrera, máximo consumo de oxígeno

RESUMEN

El objetivo de esta revisión sistemática ha sido comparar los diferentes métodos de entrenamiento de fuerza para mejorar el rendimiento en pruebas de entre 800 y 5000 m en atletismo, eventos caracterizados por altos requerimientos de capacidad aeróbica, de fuerza máxima y de potencia. La base de datos Pubmed fue empleada para buscar artículos originales acerca del entrenamiento de fuerza en medio fondistas. Para ello se introdujeron diferentes combinaciones de algunos términos como: "middle distance", "running performance", "VO2max", "running economy", "resistance training", "strength training", "concurrent training" y "plyometric training". Los artículos cuyas intervenciones fueron evaluadas con test de contrarreloj superiores a 5 km fueron excluidos. Inicialmente se recolectaron 298 artículos, de los cuales 9 fueron seleccionados atendiendo a los criterios de inclusión y exclusión. Tras un periodo de intervención con una duración de 6 a 12 semanas, en todos los artículos se observaron mejoras en parámetros fisiológicos y neuromusculares, a excepción de uno. En este estudio se apreció una tendencia a la mejora, aunque los cambios no fueron significativos. Los estudios que mayores mejoras obtuvieron, realizaron entrenamiento de fuerza con cargas del 70 % RM o superior. Además, este entrenamiento de fuerza fue combinado con ejercicios pliométricos realizados sin peso adicional o añadiendo un 30% del peso corporal. En conclusión, combinar el entrenamiento de fuerza a una intensidad del 70%RM o superior a 4-10 repeticiones con entrenamiento pliométrico, parece ser el método más efectivo para optimizar el rendimiento en carreras de medio fondo

Introduction

Within the wide range of events held in athletics, the 800 and 1500 meter sprint events are the Olympic events belonging to the middle-distance sector (Real Federación Española de Atletismo, 2020, Annex 1). Due to their physiological characteristics, the 3000 and 5000 meter races could be considered as middle-long distance and similar to those previously mentioned (Lacour et al., 1990). This is due to the fact that, in the case of national and international championships, where athletes compete for a medal, the mark is of secondary importance. Therefore, athletes use tactics with changes of pace and the last lap is run at a speed around 110% of VO2max (Billat, 2001). In abbreviated form, performance in these tests is given by the ability to cover the required distance in the shortest possible time (Ramírez-Campillo et al., 2014). On the other hand, Blagrove et al. (2018) define running performance as a complex interaction of physiological, biomechanical, psychological, environmental and tactical factors. The approximate duration of these events according to the marks made by the world elite in the 2021 outdoor season was 1'45" in 800 m, 3'30" in 1500 m, 8' in 3000 m and 13' in 5000 m (World Athletics, 2021). Given the duration of these sports events, García-Pallarés & Izquierdo (2011) state that they require high levels of aerobic capacity, maximum strength and power.

Regarding the energetic contribution of the metabolic systems, we found that in the 800 m race, the aerobic system contributes from 60 to 75% of the energy, while the anaerobic system contributes between 25 and 40%. This great variability is due to the different types of athletes who run this test. If we refer to 1500 m, it is known that 75-85% of the energy is obtained aerobically and 15-25% anaerobically (Haugen et al. 2021). On the other hand, in longer events such as the 3000 and 5000 m, the aerobic system appears to provide 85 to 95% of the energy, with 5 to 15% being the contribution of the anaerobic system (Sandford & Stellingwerff, 2019).

In predicting performance in these tests Haugen et al. (2021) suggest attending to the parameters of Maximal Oxygen Consumption (VO2max), Running Economy (RE), Anaerobic Threshold Velocity (VAT) and VO2max Velocity (vVO2max). In recent years, ER is taking a leading role in the search for the path to improved performance. This is influenced by biomechanical factors, muscle fiber distribution, age, gender and anthropometric factors (Balsalobre-Fernandez et al., 2016). In addition, SR is affected by different strength work: low loads, high loads, explosive strength and plyometric training. These different strength trainings have been shown to improve the performance of both popular athletes and moderately and highly trained athletes (Balsalobre-Fernandez et al., 2016). On the other hand, thanks to research such as that of Beattie et al. (2014) or Moore's (2016) we know that both RE and anaerobic factors, depend on rapid force generation during the ground contact phase.

However, García-Pallarés & Izquierdo (2011) state that the benefits that strength training brings to the performance of athletes will occur only in the case that the training plan is properly designed. In recent studies it was found that when comparing a group that only trained strength and another group that performed concurrent training, the former group obtained greater gains in maximal strength. This was because the second group suffered from what we know today as interference phenomena. However, several studies suggest that a properly designed and executed training protocol can minimize or even avoid this phenomenon. This will be very interesting in cyclic sports modalities whose duration ranges from 30 seconds to 8 minutes and require high demands of strength and endurance simultaneously (García-Pallarés & Izquierdo, 2011).

Jiménez-Reyes & González-Badillo (2011) state that the three main elements of strength training load are volume, intensity and frequency; to which should be added the exercise performed. An optimal relationship of these variables would cause an adaptation in the athlete, which should have a direct impact on his performance. That said, knowing how to structure strength training within a middle-distance athlete's training program correctly will allow us to improve their performance by minimizing or avoiding the aforementioned interference phenomenon.

The scientific literature affirms that weight training is an effective strategy for improving running performance. However, it does not seem to be very clear which are the best methods to work on strength and how to modulate the parameters of the load of this stimulus to achieve the most efficient results. On the other hand, evidence is found about strength work in sprinters and long distance runners, however, there seems to be a paucity of research regarding middle distance runners. Therefore, the objective of this review is to compare different strength training methods to improve performance in 800 to 5000 m events.

Method

Search strategy

In order to carry out this systematic review, a search for articles was carried out in the PubMed database. The main terms used to search for articles were: "middle distance, running performance, VO2max, running economy, resistance training, strength training, concurrent training and plyometric training. These terms and others were combined with Boolean parameters to perform the search as follows: ("middle distance" OR "800 meter" OR "1500 meter" OR "3 km") AND ("running performance" OR "running economy" OR "vVO2max" OR "VO2max speed" OR "maximal oxygen intake") AND ("resistance training" OR "strength training" OR "plyometric training" OR "concurrent training") AND ("interference phenomenon"). In addition, the Boolean parameter NOT was added to exclude the terms "marathon" and "ultra-endurance".

Inclusion criteria

This systematic review included articles related to middle-distance running up to 5 km in athletics, written in both Spanish and English. The articles whose evaluation tests included time trials of distances between 800 and 5000 meters were included. On the other hand, articles whose evaluations contained laboratory tests to assess physiological and biomechanical parameters (VO2max, RE, RFD, etc.) directly related to middle distance tests were also included. In addition, no limit was imposed as to the date on which the article was written.

Exclusion criteria

Articles whose research focused on sprinters (runners of 400 m or less) or long-distance runners (runners of distances greater than 5 km) were excluded. Articles whose post-intervention evaluation tests included time trials longer than 5 km were discarded. Includes design, participants, instrument, data analysis, etc.

Results

Figure 1 below shows the flow chart representing the item selection process. The search for articles was initiated and 298 studies were identified, and finally, 9 were included in the review.

Figure 1
Item selection flowchart

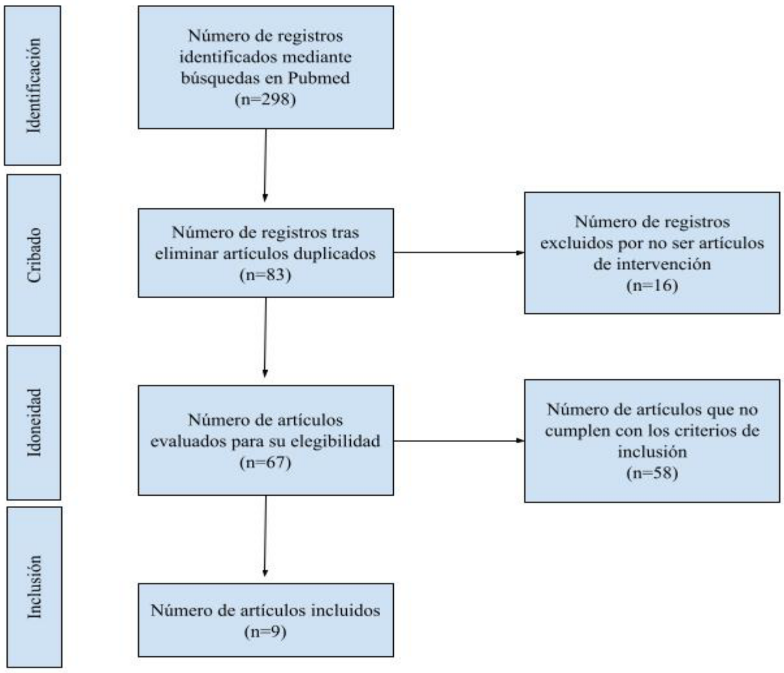

Table 1 shows the different variables and results of the selected studies. On the one hand, there are variables related to the subjects and, on the other, those related to the intervention carried out.

Table 1 shows a summary of the results of the selected articles:

Table 1

Characteristics of the studies, their participants and training programs

Study	Subjects			Research							
	n and Sex	**Age (years)**	**Experience and characteristics**	**Group design**	**Program**	**Duration**	**Training**	**Intensity**	**Running training**	**Evaluation test**	**Results**
García-Pinillos et al. (2020)	51 H + 45 M (27+24 IG / 24-21 CG)	Range between 18 - 40	Recreational runners (3-5 running sessions per week). Able to run 10 km in <50'.	Random	Plyometrics (jumping rope)	10 weeks 2-4 times/week 10-20'/week	5' of jumping rope in the warm-up of each session.	Weekly progression, starting with 30":30" (work:rest) bilateral and ending with 40":20" unilateral-alternate.	Regular training. The IG modified his warm-up routine to introduce jumping jacks. 42.1 ± 6.5 km/week	Stiffness CMJ Squat Jump Drop Jump Reactive Strength Index 3-km test	Significant improvements in GI in all variables tested, while CG did not improve significantly.
Mikkola et al. (2007)	18 H + 7 M (9+4 IG / 9+3 CG)	Range between 16-18	Post-pubertal long-distance runners with at least 2 years of long-distance running training experience.	Non-random division of the groups.	Explosive strength training	8 weeks 3 sessions/week 30-60' /session	Sprint: 5-10x30-150m Jump: alternative jumps, calf jumps, squat jumps, hurdle jumps Resistance: half squat, knee extension-flexion, calf raises, abd curls, back extensions (2-3 sets x 6-10 reps)	Low loads. Maximum execution speed.	8,8 ± 2,1 h 12.4 ± 3.0 sessions/week >95% <LT The IG exchanged 19% of the running hours for explosive strength training.	Muscle strength measurements VMART (9-10x150m) 30m Sprint 5J + CMJ Aerobic parameters	Improved MI in VMART and 30m test. Improvements in GI strength. Parameters aerobic =

Paavolainen et al. (1999)	18 H (10 IG / 8 CG)	23 ± 3 (IG)	Elite cross-country orienteering runners. VO2max (63.3 ± 2.1)	Selection of groups based on VO2max and time of the 5 km test.	Explosive strength training	9 weeks 2.7 h/week in sessions of 15-90'	Sprint: 5-10x20-100m PT: alternate jumps, CMJ, landing, hurdle jumps, 5-JUMP TEST on one leg. (30-200 jumps) RT: leg-press, knee extensor-flexor (5-20 reps.)	0-40% MR Maximum execution speed.	8,4 ± 1,7h 9 ± 2 sessions/week 84% <LT and 16% >LT The IG exchanged 32% of career hours for EST.	5 km test RE VO2max VMART Test 20m Sprint 5-Jump Test VO2MAX and LT	Improvements in the 5 km test and RE and VMART values by the IG. Improvements in the 20m test and 5-Jump test in the IG while the CG worsened. VO2max =
Ramírez-Campillo et al. (2014)	22 H + 14 M (10+8 IG / 12+6 CG)	22,1 ± 2,7	>2 years of experience in national and international competitions. 1500m MMP = 3'50" (H) - 4'27" (M) Marathon MMP = 2:32 (H) - 2:52 (M)	Random	Plyometry	6 weeks 2 sessions/week < 30'/session	2x10 Drop Jumps 20cm 2x10 Drop Jumps 40cm 2x10 Drop Jumps 60cm	Body weight. Maximum intentionality and minimum contact.	67.2 ± 18.9 km/week	CMJ + DJ 20m Sprint 2.4 km test	IG significantly improved 2.4 km and 20m test times and CMJ and DJ values compared to CG.
Saunders et al. (2006)	15 H (7 IG / 8 CG)	23.4 ± 3.2 (IG)	Highly trained national and 6 international level long-distance athletes. Mark in 3 km = 8.5 ± 0.4 min. VO2max (71.1 ± 6.0 ml/min/kg)	Random	Plyometrics + Strength training	9 weeks 3x30' /week	Back extension, Leg press, CMJ, Knee lifts (technical), Ankle jumps, Hamstring curls, Alternate-leg bounds, Skip for height, Single-leg ankle jumps, Hurdle jumps, Scissor jumps for height	Plyometry: 0 Strength training: 60%RM	107 ± 43 km/week 3 interval sessions 1 run-in of 60-150' 3 shoots of 30-60' 3-6 runs of 20-40'	RE VO2max 5-CMJ RFD	Non-significant improvements in ER, although tendency to improve in GI. VO2max = Strength data muscular =
Sedano et al. (2013)	18 H (6 EG / 6 GS / 6 ESG)	23,7 ± 1,2	Athletes (3000-5000 m) trained with a VO2max >65 and more than 4 years of training. National level competitors in Spain.	Random	Plyometric Strength Strength-endurance	12 weeks 2 sessions/week	ST: Barbell Squat, Lying leg curl, Seated calf raises and Leg extension PT: hurdle jumping (40 cm) and horizontal jumps	3x7 70%RM + 3x10 PLYO (SG) 3x20 40%RM (ESG)	6 sessions/week Runs and fartleks of 0.5-1.5h Series training	CMJ 25" Hopping test 1RM RE VO2max 3-km test	SG obtained improvements in all tests
	17 H	25 ± 4	Training history of	Random	Plyometry	6 weeks	Squat Jump, Split	Progression		RE	The IG improved the

Spurrs et al. (2003)	(8 IG / 9 CG)		10 ± 6 years.			2-3 sessions/week	Scissor Jump, Double Leg Bound, Alternate leg bound, Single Leg forward hop, Depth Jump, Double leg hurdle jump, single leg hurdle hop	from 60 to 180 contacts per week. Body weight. Maximum intentionality and minimum contact.	Regular training. 60-80 km/week	VO2max Lactic Threshold Force parameters CMJ 5-Bound Test 3-km test	values of the 3 km test, RE, CMJ, 5-bound test and strength parameters. VO2max and LT = No changes were observed in the GC.
Støren et al. (2008)	9 H + 8 M (4+4 IG / 5+4 GC)	28,6 ± 10,1 (IG)	Trained athletes VO2max 61.4 ± 5.1 Mark in 5-km= 1122,4 ±5 8,4	Division according to age and 5 km mark, randomized.	Maximum strength training	8 weeks 3 sessions/week	4x4 Half Squat	4RM	Regular resistance training	RE VO2max MORE 1RM Half Squat RFD	Improvements of MI in MRI, RFD, RE and MAS tests. VO2max =
Trowell et al. (2022)	18 H +12 M (9+6 IG / 9+6 CG)	33.1 ± 7.5 (IG)	Moderately trained runners. >30km/week	Random	Plyometrics + Strength training	10 weeks 2 sessions/week	Ankle bouncing, Back Squat, Hurdle Jumps (40 cm), Frontal Plank, High-knee drill, Single-leg deadlift, Split Squat Jump, Side-Stepping, CMJ, DJ, Glute Bridge	ST: 70%RM, 10 reps. PLYO: body weight or 30%BW	Regular resistance training	2-km test Time to exhaustion VO2max RE	Improvement in 2-km test time and "time to exhaustion" in VO2max test. VO2max = RE =

Note. M/F = men/women, IG/CG = intervention/control group, CMJ = countermovement jump, DJ = drop jump, 5J = 5-jump test, RM = repetition maximum, RFD = rate of force development, RE = running economy, VO2max = maximal oxygen consumption, LT = lactic threshold, MAS = maximal aerobic speed, VMART = maximal anaerobic running test, ST = strength training, RT = resistance training, PT = plyometric training, EST = explosive strength training, EG = endurance-only group, ESG = endurance-strength group, SG = strength group, MMP = personal best, BW = body weight, (=) = no significant variation of the values

Discussion and conclusions

The objective of this systematic review was to compare the effects of different strength training methods on the performance of both high-level and recreational athletes in middle-distance events. To test the effect of these programs on performance, different types of assessments have been used. On the one hand, we found those of a physiological nature, which evaluated predictors of performance such as RE, VO2max or LT (Brandon, 1995). Other assessments, measured neuromuscular parameters, highly related to sports performance as is the case of CMJ (Aragón-Vargas & Gross, 1997) and other jumping skills, also related to performance in 800m, 3000m and 5000m events (Hudgins et al., 2013). In terms of strength, the most notable tests that have been used are the 1RM of different exercises and the RFD, both highly related to the improvement of RE (Hoff & Helgerud, 2003). Finally, in a more direct way and similar to the competitive reality, time trials of distances from 2.4 km to 5 km were also carried out. Understanding sport performance as a complex interaction of factors (Blagrove et al., 2018), the studies previously analyzed, have compared a mixture of those previously described.

In the case of the articles analyzed, it was observed that 3 types of programs were mainly applied: plyometric training, strength training (with different intensities) and plyometric and strength training together. As for those who used plyometry only, in the studies of García-Pinillos et al. (2020) and Ramírez-Campillo et al. (2014), significant improvements were observed in neuromuscular assessments, jumping ability and time trial times. In addition to these improvements over the control groups, in the intervention of Spurrs et al. (2003) improved ER values without varying VO2max and LT parameters. This improvement was caused by an increase in the muscle-tendon stiffness of the lower limbs, which increases reactive strength and decreases energy cost (Spurrs et al., 2003). The only program that included strength training only was that of Støren et al. (2008). In this study, which implemented maximal strength work, improvements similar to those obtained by plyometric programs were achieved, improving RFD, RM, CMJ and aerobic values, while maintaining pre-test values in VO2max. Again, this suggests a relationship between the RFD of the musculature involved in running and the ER (Støren et al., 2008). Finally, the rest of the interventions combined plyometrics with strength training at different intensities. In the case of Mikkola et al. (2007), Paavolainen et al. (1999), Sedano et al. (2013) and Trowell et al. (2022), participants improved in neuromuscular parameters, anaerobic test (VMART) and time trial times, again maintaining initial VO2max data. However, in the study by Saunders et al. (2006) did not show significant improvements by combining plyometrics and strength, although a tendency to improve RE was observed. This appears to be because high-level athletes will require longer periods of training and/or higher intensity loads to see significant improvements.

Considering load parameters such as intensity and volume of the exercises proposed by the studies, we observed from interventions that only used body weight, to others that approached the maximum external load to perform the exercises. Almost all of the studies that included jumping and other plyometric exercises used only body weight, however, there is a progression of loading in terms of volume (number of contacts) and density in the case of the articles by Spurrs et al. (2003) and García-Pinillos et al. (2020). The only study that used external loading in plyometric exercises was that of Trowell et al. (2022), where 30% of body weight was carried in CMJ, DJ and Split Squat Jump. In the case of the intervention by Ramírez-Campillo et al. (2014) there is also a variation in intensity, going through 20, 40 and finally 60 cm in the height from which the DJ was performed. On the other hand, the studies by Mikkola et al. (2007) and Paavolainen et al. (1999), chose to perform strength exercises with low loads at maximum speed, combining them with plyometrics with their own body weight and sprints of 20 to 150 m. While the participants in the studies by Saunders et al. (2006), Sedano et al. (2013) and Trowell et al. (2022), used loads of 60% in the first study and 70% of the RM in the last two, with superior improvements in the group that worked with a higher RM. On the other hand, the protocol that proposed the highest % of RM for strength training was that of Støren et al. (2008), where the subjects increased their load by 2.5 kg in the case of being able to perform one more repetition than programmed, indicating that their training was of maximum intensity with few repetitions. Therefore, regardless of the % of MR used, all subjects improved their pre-intervention values. However, according to the study by Sedano et al. (2013) it seems to be more effective to work with a moderate-high RM %, in this case 70% to optimize performance if compared to an intensity of 40%. Finally, the intervention with the longest duration was that of Sedano et al. (2013) with a total of 12 weeks with a frequency of 2 weekly sessions. In contrast, the studies of shorter duration were 6 weeks with a frequency of 2 and 2 or 3 weekly sessions in the case of Ramírez-Campillo et al. (2014) and Spurrs et al. (2003) respectively. This suggests that the minimum duration to observe improvements in performance was 6 weeks, where 2 plyometric sessions were performed weekly.

Before drawing conclusions, it is necessary to look at the characteristics of the subjects who participated in the studies, as there is great diversity. In the first place, the study by Saunders et al. (2006), since it is the only one where improvements were not significant. Possibly for a sample of highly trained athletes at a national and international level, it may take more than 9 weeks for the improvement to be significant. In addition, it is possible that the intensity (60% MR) was not sufficient, compared to the study by Sedano et al. (2013), where despite the fact that the subjects had a national competitive level, the group that worked at 70% RM for 12 weeks, obtained greater improvements compared to the rest. On the other hand, in the study by Ramírez-Campillo et al. (2014) also improved the performance of high-level athletes in less time (6 weeks) but did employ a progression of loads by tripling the plyometric intensity from 20 to 60 cm in DJ height. On the contrary, it seems that low intensity is sufficient in the case of recreational subjects (García-Pinillos et al., 2020) and adolescent subjects (Mikkola et al., 2007). This suggests the need to adjust both the duration of the training period and the intensity and other parameters of the load, depending on the level of the subjects, since the lower the level, the lower the stimulus needed to produce adaptations and vice versa.

The main limitations of the present systematic review are related to the number of studies analyzed and their sample characteristics. Although there is a large number of articles linking strength training to improved athletic performance, the availability of studies comparing strength training programs with middle-distance performance is very limited. On the other hand, most studies use a sample whose specialty within middle-distance running is inclined towards longer events such as the 3000m and 5000m, and there are no interventions that demonstrate the validity of these programs to improve performance in 800m events. Finally, it should be noted that most of the studies show low ecological validity, since they measure performance through laboratory tests that are very expensive and to which most trainers do not have access.

The main objective of this systematic review was to compare different strength training programs to improve performance in middle-distance events in athletics. It appears that strength training combined with plyometrics produces the greatest improvements in running performance. The parameters of the load must always be individualized according to the characteristics of each subject, however, the following are some guidelines to optimize the programming of the training. This review suggests using a percentage equal to or greater than 70% RM to work strength with 2 to 4 sets of 4 to 10 repetitions. As for plyometrics, it is proposed to increase the external load progressively. This increase in load can be generated by varying any variable related to the external load such as height, number or ballast in the jumps. However, in lower-medium level subjects, lower intensity strength and/or plyometric training could be sufficient to generate adaptations that optimize sports performance. Finally, more research is needed to reaffirm these conclusions.

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