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Research article

Jumping Interval Training: An Effective Training Method for Enhancing Anaerobic, Aerobic, and Jumping Performances in Aerobic Gymnastics

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Abstract
The aim of this study was to compare the effects of jumping interval training (JIT) and running high-intensity interval training (HIIT) on the aerobic, anaerobic and jumping performances of youth female aerobic gymnasts. A randomized controlled study was conducted over an 8-week period, involving 73 youth female athletes (16.2 ± 1.3 years old) of aerobic gymnastics. The study comprised two experimental groups (JIT and HIIT) and a control group. Participants in the experimental groups engaged in two additional training sessions per week alongside their regular training regimen, while the control group followed their usual training routine. Before and after the intervention period, gymnasts were assessed for their performance in the countermovement jump test (CMJ), the specific aerobic gymnastics anaerobic test (SAGAT) and the 20-m multistage fitness test. Significant interactions time × group were found in SAGAT ($p < 0.001$; $\eta_p^2 = 0.495$), CMJ ($p < 0.001$; $\eta_p^2 = 0.338$) and 20-m multistage fitness test ($p < 0.001$; $\eta_p^2 = 0.500$). The time × group analysis post-intervention revealed significantly lower scores in SAGAT for the control group compared to the JIT ($p = 0.003$) and HIIT ($p = 0.034$). Additionally, significantly higher scores were observed for the JIT group in the CMJ test compared to the HIIT ($p = 0.020$) and control ($p = 0.028$) groups following the intervention. Finally, the 20 m multistage fitness test post-intervention revealed significantly lower scores for the control group compared to JIT ($p < 0.001$) and HIIT ($p < 0.001$). Both JIT and HIIT are recommended training strategies to adopt in aerobic gymnastics for significantly improving the aerobic and anaerobic performances of athletes. However, JIT may be particularly relevant to use as it offers additional benefits in improving vertical jumping performances.

Key words: Gymnastics, high-intensity interval training, aerobic fitness, anaerobic fitness, countermovement jump.

Introduction

Aerobic gymnastics presents considerable demands on cardiorespiratory and metabolic systems, engaging both aerobic and anaerobic pathways extensively to support intermittent, high-intensity routines (Kyselovičová and Danielová, 2012). Physiologically, athletes must exhibit a well-prepared cardiovascular fitness (Cuce et al., 2021). Furthermore, it has been suggested that a greater relative dependence on anaerobic energy is evident among athletes performing at higher levels, highlighting that success in aerobic gymnastics correlates not only with superior movement skills but also with the intensity and complexity of routines (Aleksandraviciene et al., 2015). In addition to possessing well-prepared metabolic systems, athletes must also develop muscular strength and endurance across their upper and lower limbs to effectively execute dynamic and ballistic movements, while ensuring the necessary endurance to sustain performance across all routines (Puiu and Dragomir, 2020). Thus, achieving optimal performance in aerobic gymnastics depends on a delicate balance among energy systems, physiological adaptations, and muscular capabilities, all of which collectively enhance athletes' performance (Lamošová et al., 2021).

High-intensity interval training (HIIT) as a training method can be a promising avenue for enhancing aerobic and anaerobic gymnastics performance, supported by scientific evidence highlighting its multidimensional physiological benefits (Buchheit and Laursen, 2013a; b). Incorporating HIIT into aerobic gymnastics routines can elevate cardiovascular capacity, crucial for sustaining prolonged high-intensity efforts during routines (Gibala and McGee, 2008). The intermittent nature of HIIT may replicate the dynamic nature of gymnastic performances, fostering adaptability and efficiency in energy utilization. Moreover, HIIT stimulates mitochondrial biogenesis and enhances muscle oxidative capacity (Hoshino et al., 2016), crucial for enduring aerobic demands and facilitating rapid recovery between explosive movements inherent in gymnastic routines. Additionally, HIIT augments anaerobic glycolytic pathways (Abe et al., 2015), optimizing power output necessary for executing complex, powerful and repeated movements (Boullosa et al., 2022).

While most studies on HIIT concentrate on popular forms such as running or cycling, exploring other modalities of movement is essential. For example, jumping, closely associated with the characteristics of certain sports like aerobic gymnastics, offers an interesting approach for investigation and application (Venegas-Carro et al., 2023). Considering the considerable muscular demands inherent in aerobic gymnastics, which require both muscular endurance and power for executing repeated and high-intensity jumps, integrating HIIT could yield additional benefits by specifically targeting and enhancing jumping performance. One possible effective option is to incorporate jumping interval training (JIT) protocols (Kramer et al., 2019), designed to enhance muscular endurance and power while also targeting improvements in metabolism and the systems supporting the bioenergetics of the sport.

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By alternating between periods of high-intensity effort and recovery, JIT not only strengthens aerobic and anaerobic capacities but also may focuses on developing muscle fiber coordination, thereby enhancing the explosive and endurance strength necessary for executing complex gymnastic movements (Ache-Dias et al., 2016).

Although the promising positive impact of HIIT and JIT on aerobic and anaerobic performance in gymnastic athletes is a hypothesis, experimental studies conducted in this population remain scarce (Afroundeh et al., 2020; Abuwarda et al., 2024). In one study involving thirty beginner children, it was observed that continuous jumping combined with anaerobic training effectively improved maximal oxygen uptake (Afroundeh et al., 2020). In another study, HIIT was performed using muscular endurance exercises repeated on stable and unstable platforms, demonstrating significant effectiveness in improving specific shuttle run and vertical jump tests in youth gymnasts (Abuwarda et al., 2024).

Considering that HIIT and JIT can significantly improve aerobic gymnasts in both their aerobic and anaerobic performance, as well as their jumping performances, and given the intermittent and intense nature of this sport, it is hypothesized that both HIIT and JIT could be advantageous. Furthermore, comparing traditional running HIIT with the more specific JIT offers coaches and practitioners new insights into how these modalities can be tailored to the specificity of the training context. Considering the limited research published on the effects of HIIT in gymnastics (Afroundeh et al., 2020; Abuwarda et al., 2024), and the little that is known does not explore the possibilities of using training modalities such as JIT, there is an opportunity to understand the effectiveness of this training method in enhancing key physical fitness variables among athletes. Therefore, the aim of this study was to compare the effects of JIT and running HIIT on the aerobic, anaerobic, and jumping performances in youth female aerobic gymnasts.

Methods

Participants

The a priori sample size was computed to accommodate an effect size of 0.2, accounting for three distinct groups and two measurements, with the objective of achieving a statistical power of 0.85 and maintaining a significance level of 0.05 for F tests, specifically ANOVA repeated measures, within-between interaction. Following analysis with G*power software (version 3.1.9., Universität Düsseldorf, Germany), it was recommended that the study include 72 participants.

After recruitment into the aerobic gymnastics teams, 75 eligible participants were identified. However, upon applying the following eligibility criteria: (i) participation in both evaluation moments, (ii) having a minimum of two years of experience in the sport, (iii) attending at least 85% of the regular training sessions, (iv) not experiencing injury or illness throughout the experiment or in the month preceding the study's commencement, (v) not being enrolled in additional training programs besides aerobic gymnastics training, an (vi) being female, 73 participants were enrolled in the study and distributed among the three groups.

Overall, the 73 female participants had an average age of 16.2 ± 1.3 years, height of 1.61 ± 0.03 cm, and body mass of 52.7 ± 2.4 kg. These athletes competed at the regional levels, engaging in 4 to 5 training sessions per week. The participant characteristics for each group are presented in Table 1.

Table 1. Descriptive statistics (mean ± standard deviation) for participant characteristics within each group.

	JIT	HIIT	Control
N	24	24	25
Age (years)	16.3 ± 1.2	16.2 ± 1.3	16.2 ± 1.4
Body mass (kg)	52.7 ± 2.4	52.8 ± 2.4	52.6 ± 2.5
Height (cm)	1.61 ± 0.03	1.61 ± 0.04	1.61 ± 0.03

JIT: jumping interval training; HIIT: running high-intensity interval training

The gymnasts and their parents or legal guardians were informed about the study protocol and its context. After voluntarily agreeing to participate, the legal guardians signed an informed consent form. The study adheres to the ethical standards outlined in the Declaration of Helsinki, and the study protocol received approval from the Ethics Committee of Tianjin Institute of Physical Education under code number TJUS2024/016.

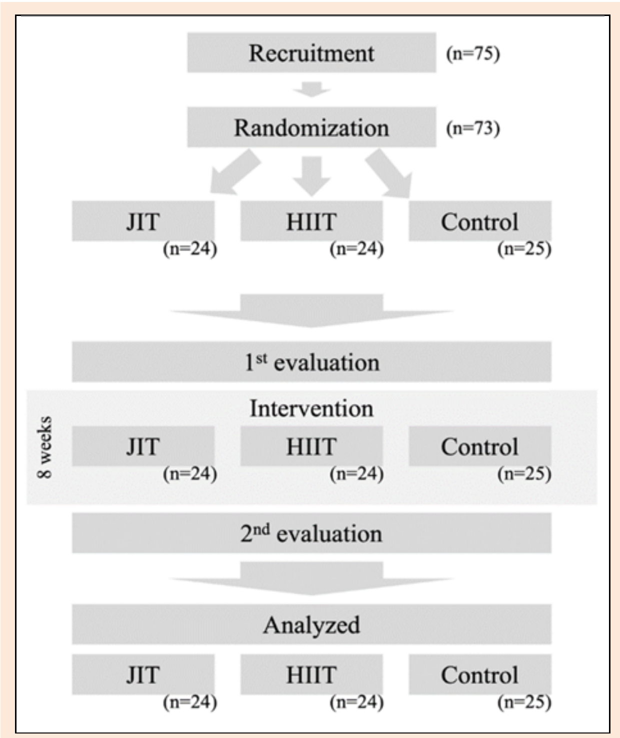

Figure 1. Study design and participant flow.

Design and methodological procedures

The study employed a randomized controlled design, wherein two experimental intervention groups (HIIT and JIT) were introduced alongside the regular training regimen. A control group solely engaged in regular aerobic gymnastics training (Figure 1). Convenience sampling was utilized to recruit participants from aerobic gymnastics teams. Simple randomization was conducted using opaque envelopes randomly assigned to gymnasts before the first evaluation, offering equal chances of being assigned to either group. The randomization was carried out by a researcher who did not participate in the evaluations, aiming to ensure allocation concealment. Evaluations occurred one week before the intervention beginning and immediately after the 8th week. Independent researchers conducted these evaluations, remaining blinded to group assignments.

Assessment
The evaluations were conducted twice, both before and after the intervention period, on the same days of the week to ensure the consistency of conditions. These evaluations took place indoors in the afternoon. Preceded by a 48-hour rest period following the latest training session, the evaluations followed a specific order: (i) collection of demographic data, (ii) anthropometric evaluations, (iii) warm-up (consisting into 5 minutes running, 15 minutes dynamic stretching and 5 minutes jumping drills, (iv) countermovement jump (three repetitions), (v) specific aerobic gymnastics anaerobic test (SAGAT), and (vi) 20-m multistage fitness test. Each assessment test was separated by a 5-minute rest interval. All participants underwent the assessments in the same order and sequence during both evaluation periods.

Anthropometrics
Basic anthropometric measurements were conducted by assessing the height and body mass of participants. Height was measured using a stadiometer (Seca 217, Seca, Hamburg), while body mass was measured with an electronic scale (SECA 813; Seca GmbH & Co., Hamburg, Germany) to the nearest 0.1 kg, with participants wearing leotards for consistency.

Countermovement jump
Participants were instructed to perform three maximal countermovement jumps (CMJ), with a 1-minute rest between each jump. They were instructed to maintain extended knees and keep their hands on their hips throughout the aerial phase of the jump, landing back onto the floor afterward. CMJ performance was measured using the MyJump 2 mobile application (version 1.0.8), which utilizes video images to identify flight time and estimate jump height. This application accuracy and precision had been previously confirmed (Haynes et al., 2019), as evidenced by the correlation values obtained in comparison to force plates for the variable of jump height (ranging from 0.80 to 0.96). The average jump height from the three attempts was selected for data analysis.

Specific aerobic gymnastics anaerobic test
The Specific Aerobic Gymnastics Anaerobic Test (SAGAT) involves executing gymnastic-specific elements in a maximal repeated sprint format within a total timeframe of 80–90 seconds (Alves et al., 2015). It consists of 2 sets, each comprising 6 consecutive bouts. Each bout includes a "tuck jump", followed by a drop to perform two "push-ups" and one "L-support". The study assessed the concurrent validity of the test in comparison to the Wingate test and confirmed its validity (Alves et al., 2015). The correlation coefficients between the lower-body Wingate test and SAGAT performance ($r = -0.69$), as well as between the upper-body Wingate test and SAGAT performance ($r = -0.67$), were found to support this confirmation (Alves et al., 2015). Additionally, the reliability of the test was observed, with no significant differences observed in the time taken to complete the SAGAT across repeated trials ($p = 0.84$; ICC = 0.97) (Alves et al., 2015). The same researchers assessed the gymnasts' performances during the test by monitoring the correctness of the elements performed and controlling the time of execution using a digital stopwatch. The time taken to complete the test (measured in seconds) was utilized for further data analysis.

20-m multistage fitness test
Participants underwent the 20-m multistage fitness test (Léger et al., 1988), which has been utilized to assess the aerobic capacity of gymnasts (Salse-Batán et al., 2022). This test has been confirmed as reliable for measuring aerobic fitness, as indicated by the non-significant bias observed between the two administrations of the test in a previous study ($p = 0.190$) (Cooper, 2005). However, it tends to underestimate maximal oxygen uptake, as evidenced by the values obtained in the concurrent validity analysis ($p = 0.004$) (Cooper, 2005). Consequently, we have not estimated maximal oxygen uptake; instead, we have utilized the final test score (i.e., total distance) as a general indicator of aerobic fitness.

The test begins with an initial speed of 8.5 km/h, and the frequency of the audio beep signals increases by 0.5 km/h each minute until the gymnasts are unable to reach the markers at the sound of the beep. The test concludes when the gymnasts are unable to achieve the marker for the second time due to fatigue. The total distance completed in meters was collected as a measure of aerobic performance.

Intervention
The gymnasts assigned to the experimental groups participated in additional JIT or HIIT sessions, which were supervised by dedicated researchers who were certified and had extensive experience in sports sciences and sports training. These sessions took place twice a week, with a 48-hour interval between them. Each session was conducted before the regular aerobic gymnastics training session. Before engaging in the experimental interventions, the gymnasts performed a standardized warm-up that included 5 minutes of running, 15 minutes of dynamic stretching, and 5 minutes of jumping drills.

The JIT regimen entailed four to five sets, each lasting 30 to 40 seconds, during which participants engaged in maximal continuous bilateral countermovement jumps (Table 2). These jumps were synchronized with an auditory cue, aiming to maintain a pace of 1.1 to 1.0 jumps per second (Ache-Dias et al., 2016; Kramer et al., 2019). The rest period between bouts was set at 30 seconds. This training methodology was informed by previous studies (Ache-Dias et al., 2016; Kramer et al., 2019) that recommended

Table 2. Characteristics of the jumping interval training (JIT) and running interval training (HIIT).

	JIT	JIT	HIIT	HIIT
	Session 1	Session 2	Session 1	Session 2
Week 1	4×30'':30'' at 1.1 jump/s	4×30'':30'' at 1.1 jump/s	4×30'':30'' at 110% MAS	4×30'':30'' at 110% MAS
Week 2	4×30'':30'' at 1.1 jump/s	4×30'':30'' at 1.1 jump/s	4×30'':30'' at 110% MAS	4×30'':30'' at 110% MAS
Week 3	4×40'':30'' at 1 jump/s	4×40'':30'' at 1 jump/s	4×40'':30'' at 105% MAS	4×40'':30'' at 105% MAS
Week 4	4×40'':30'' at 1 jump/s	4×40'':30'' at 1 jump/s	4×40'':30'' at 105% MAS	4×40'':30'' at 105% MAS
Week 5	5×30'':30'' at 1.1 jump/s	5×30'':30'' at 1.1 jump/s	5×30'':30'' at 110% MAS	5×30'':30'' at 110% MAS
Week 6	5×30'':30'' at 1.1 jump/s	5×30'':30'' at 1.1 jump/s	5×30'':30'' at 110% MAS	5×30'':30'' at 110% MAS
Week 7	5×40'':30'' at 1 jump/s	5×40'':30'' at 1 jump/s	5×40'':30'' at 105% MAS	5×40'':30'' at 105% MAS
Week 8	5×40'':30'' at 1 jump/s	5×40'':30'' at 1 jump/s	5×40'':30'' at 105% MAS	5×40'':30'' at 105% MAS

MAS: maximal aerobic speed.

30 and 40-second work durations for maximal continuous jumping. Additionally, the chosen rest intervals between sets were based on research suggesting specific rest periods to optimally target both aerobic and anaerobic metabolisms (Kramer et al., 2019).

The HIIT protocol followed a similar structure, utilizing comparable durations and regimens but incorporated running-based exercises paced according to the maximal aerobic speed. The maximal aerobic speed was estimated in the week prior to the beginning of the study, during an independent session, using a 5-minute test that has been demonstrated to be valid and reliable for measuring maximal aerobic speed (Berthon et al., 1997). The HIIT sessions employed intensities ranging from 105% to 110% of maximal aerobic speed, as recommended by previous studies for the work periods in this training modality (Buchheit and Laursen, 2013a).

The control group exclusively participated in standard aerobic gymnastics training sessions, without exposure to any other specific conditioning training apart from the regular physical and technical training administered by their coaches. These sessions typically lasted between 80 to 120 minutes and included both general and specific warm-up strategies. The warm-up phase incorporated both static and dynamic stretching exercises, alongside multi-jump activities, before transitioning into a targeted strength and conditioning phase of the training, primarily emphasizing muscular endurance. The core phase of the training was on the development of technical elements and gymnastics routines. The session concluded with a cooldown phase, centered around stretching exercises. In contrast, the experimental groups, while also engaging in the regular training like the control group, received additional specific JIT or HIIT training supplements, administered alongside their regular aerobic gymnastics training sessions.

Statistical analysis

The a priori sample size was computed to accommodate an effect size of 0.2, accounting for three distinct groups and two measurements, with the objective of achieving a statistical power of 0.85 and maintaining a significance level of 0.05 for F tests, specifically ANOVA repeated measures, within-between interaction. Following analysis with G*power software (version 3.1.9., Universität Düsseldorf, Germany), it was recommended that the study include 72 participants.

After exploring possible outliers, descriptive statistics were reported using means and standard deviations. Prior to conducting inferential statistics, the normality of the sample was assessed and confirmed using the Kolmogorov-Smirnov test ($p > 0.05$), while the assumption of homogeneity was verified with Levene's test ($p > 0.05$). Given the study design (two assessments for three groups), a mixed ANOVA was employed to analyze interactions between time and groups. The analysis included calculation of partial eta squared (η_p^2). Additionally, post-hoc tests were performed using the Bonferroni test. Statistical analyses were conducted using JASP software (version 0.18.3, University of Amsterdam, The Netherlands) with a significance level set at $p < 0.05$.

Results

The between-group analysis indicated that there were no significant differences between the groups in the pre-evaluation for the SAGAT ($F_{2,70} = 0.234$; $p = 0.792$; $\eta_p^2 = 0.007$), CMJ ($F_{2,70} = 0.159$; $p = 0.854$; $\eta_p^2 = 0.005$) and 20-m multistage fitness test ($F_{2,70} = 3.091$; $p = 0.052$; $\eta_p^2 = 0.081$).

Significant interactions time × group were found in SAGAT ($F_{2,70} = 34.280$; $p < 0.001$; $\eta_p^2 = 0.495$), CMJ ($F_{2,70} = 17.835$; $p < 0.001$; $\eta_p^2 = 0.338$) and 20-m multistage fitness test ($F_{2,70} = 34.935$; $p < 0.001$; $\eta_p^2 = 0.500$).

The time × group analysis post-intervention revealed significantly lower scores in SAGAT for the control group compared to the JIT (-1.206s; p = 0.003) and HIIT (-0.911s; p = 0.034). Additionally, significantly higher scores were observed for the JIT group in the CMJ test compared to the HIIT (-1.375cm; p = 0.020) and control (-1.302cm; p = 0.028) groups following the intervention. Finally, post-intervention revealed significantly lower scores in 20-m multistage fitness test for the control group compared to the JIT (-80.967m; p < 0.001) and HIIT (-56.800m; p < 0.001). Descriptive statistics are presented in Figure 2.

The group × time analysis (Figure 3) revealed that JIT significantly improved scores in the SAGAT (pre 81.0 ± 1.4s and post 79.4 ± 1.4s; p < 0.001), CMJ (pre 31.0 ± 1.6cm and post 32.5 ± 1.2cm; p < 0.001), and 20-m multistage fitness test (pre 1307.5 ± 47.5m and post 1424.2 ± 40.0m; p < 0.001). Additionally, HIIT significantly improved scores in the SAGAT (pre 81.2 ± 1.3s and post 79.7 ± 1.1s; p < 0.001), CMJ (pre 30.7 ± 2.4cm and post 31.2 ± 2.0cm; p = 0.002) and 20-m multistage fitness test (pre 1276.7 ± 49.6m and post 1400.0 ± 40.0m; p < 0.001). Finally, control group significantly improved scores in the SAGAT (pre 81.1 ± 1.3s and post 80.6 ± 1.1s; p < 0.001), CMJ (pre 30.9 ± 2.3cm and post 31.2 ± 1.8cm; p = 0.041) and 20-m multistage fitness test (pre 1275.2 ± 55.5m and post 1343.2 ± 51.5m; p < 0.001).

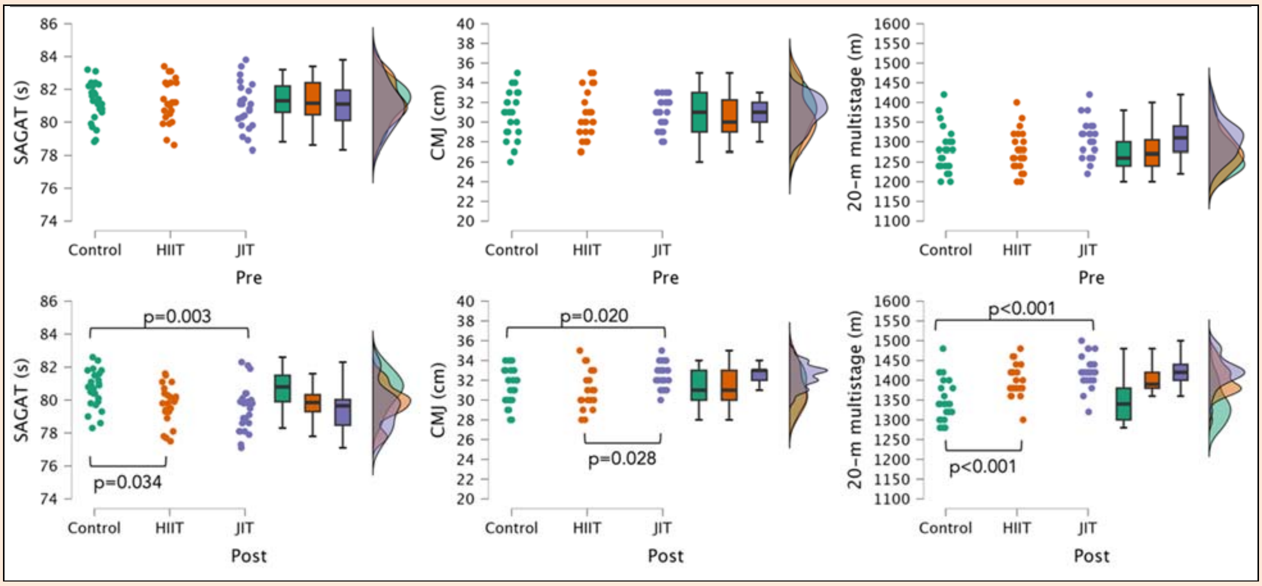

Figure 2. Descriptive statistics for the between-group comparison in the main outcomes. Specific Aerobic Gymnastics Anaerobic Test (SAGAT), countermovement jump (CMJ), and 20-meter multistage fitness test. JIT: jumping interval training; HIIT: running interval training

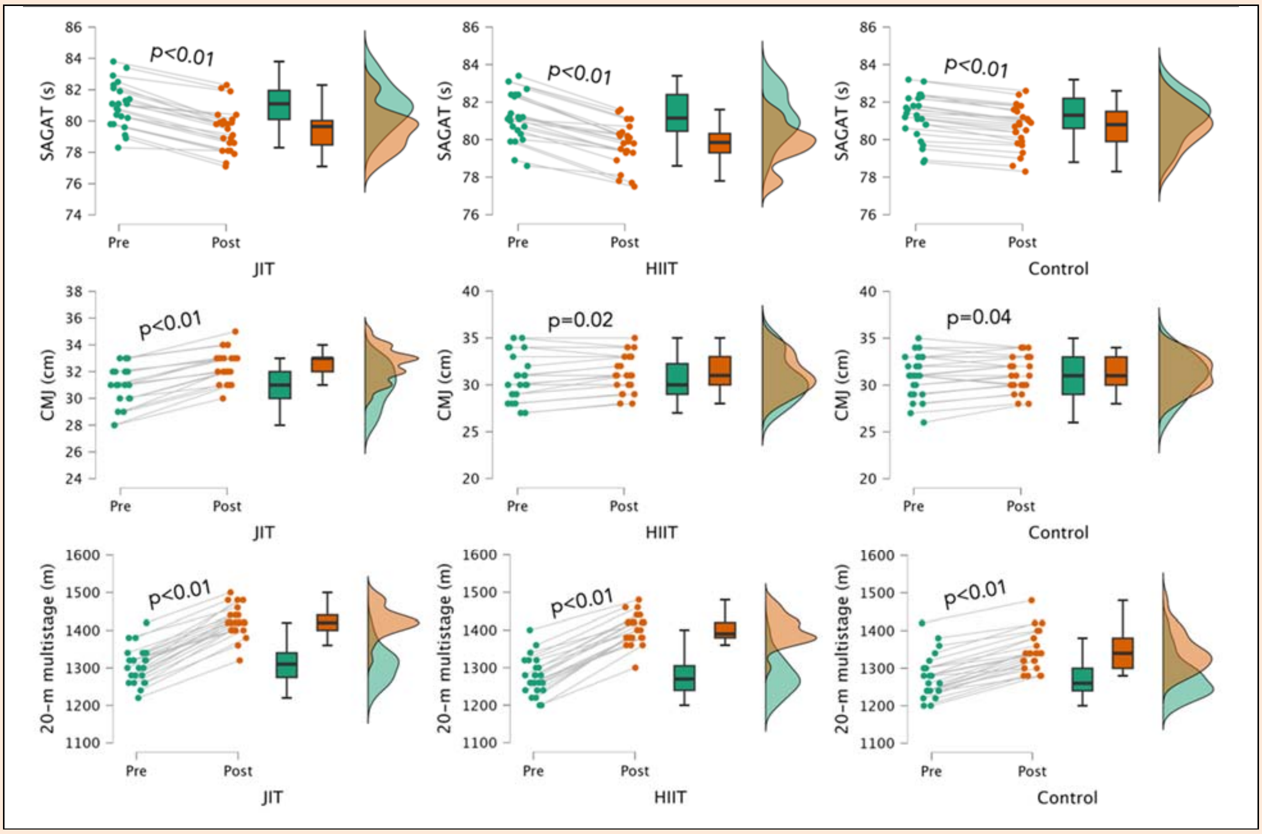

Figure 3. Descriptive statistics for the within-group comparison in the main outcomes. Specific Aerobic Gymnastics Anaerobic Test (SAGAT), countermovement jump (CMJ) and 20-meter multistage fitness test. JIT: jumping interval training; HIIT: running interval training

Discussion

The main findings of our study indicate that supplementing regular aerobic gymnastics training with either JIT or HIIT significantly enhances both aerobic and anaerobic performances compared to athletes only engaged in standard training sessions. Furthermore, our observations highlight JIT's superiority over HIIT and the control group in enhancing jumping performance, as measured by CMJ. Considering the specificity of aerobic gymnastics, which depends on a well-prepared aerobic and anaerobic fitness level, and given that many movements involve multiple jumps, our findings suggest that JIT could serve as a more fitted training approach. It can be effectively introduced to enhance these qualities in athletes while maintaining the sport's training specificity.

Although being the first study, to our knowledge, to compare both JIT and HIIT with a control group in aerobic gymnastics athletes, it was observed, as expected, that those engaged in JIT and HIIT significantly improved anaerobic performance, as measured by SAGAT. A previous study conducted on another population, specifically recreational runners, demonstrated that anaerobic power and capacity were significantly enhanced by JIT (Ache-Dias et al., 2016), which aligns with our findings. Our study is also in line with previous research demonstrating that HIIT significantly enhances anaerobic performance (Stöggl and Björklund, 2017).

In the case of JIT, we specifically employed the regimen that, in a previous study (Kramer et al., 2019), showed a greater impact on lactate accumulation and a higher percentage of time spent above 90% of maximal oxygen uptake. Additionally, in HIIT, we utilized short intervals that also targeted aerobic and anaerobic power through stimulation intensities exceeding 85% of maximal heart rate (Chang et al., 2020). It is expected that both training regimens would foster positive adaptations in anaerobic performance, as both JIT and HIIT have the potential to induce changes in the glycolytic energy system (Abe et al., 2015). This enhancement improves the ability to rapidly produce ATP during high-intensity efforts, which is crucial for anaerobic performance (Brandão et al., 2020).

The repetitive exposure to vigorous exercise stimulates adaptations aimed at enhancing buffering capacity (Callahan et al., 2021). This enhancement supports the ability to withstand changes in pH levels during exercise by buffering the buildup of lactate and hydrogen ions (Lemminger et al., 2022). Given that both JIT and HIIT induce significant increases in lactate accumulation and the duration spent at high intensities, there is a heightened reliance on anaerobic metabolism (Afroundeh et al., 2020). The adaptations observed in buffering capacity serve to bolster anaerobic performance by facilitating the efficient removal and recycling of metabolic byproducts, thereby postponing the onset of fatigue (Gabriel and Zierath, 2017). This is crucial for sustaining high-intensity efforts and enhancing overall performance in activities dependent on anaerobic energy systems, such as aerobic gymnastics.

Additionally, our research also revealed that both JIT and HIIT were significantly more effective in improving aerobic capacity compared to the control group. These findings align with studies that have demonstrated how continuous jumping, combined with anaerobic training, effectively enhances maximal oxygen uptake (Afroundeh et al., 2020). Furthermore, our results align with research that employs HIIT alongside muscular endurance exercises, repeated on both stable and unstable platforms, demonstrating improvements in specific shuttle run among youth gymnasts (Abuwarda et al., 2024).

One important mechanism that likely explains the favorable adaptations in aerobic performance is the enhancement of cardiac function (Astorino et al., 2012), including increased stroke volume and cardiac output, which leads to more efficient oxygen delivery to working muscles (MacInnis and Gibala, 2017). Moreover, intense interval training also stimulates mitochondrial biogenesis and oxidative enzyme activity within muscle fibers (Pengam et al., 2021), thereby enhancing the muscles' capacity to utilize oxygen for energy production (Rosenblat et al., 2022). Additionally, it has been documented that intense interval training promotes vascular adaptations, such as increased capillarization and improved blood vessel function (Khalafi et al., 2022), which facilitate oxygen delivery to muscles.

The distinguishing result revealed by the current experimental study was that JIT significantly outperformed both the HIIT and control groups in enhancing vertical jumping performance, as measured by the CMJ test. Our findings are consistent with a previous study conducted on runners (Ache-Dias et al., 2016), which reported significant improvements in CMJ following exposure to JIT.

JIT, compared to HIIT, has shown superior efficacy in enhancing CMJ performance, due to its specific biomechanical and neuromuscular adaptations. During JIT exercises, the stretch-shortening cycle is extensively engaged (McCaulley et al., 2007), involving rapid muscle lengthening followed by immediate shortening, leading to potentiation of subsequent contractions (Suchomel et al., 2016). This process enhances the utilization of elastic energy stored in tendons, facilitating greater force production during jumps (Wade et al., 2018). Additionally, jumping intervals require explosive force generation, targeting fast-twitch muscle fibers more effectively than running intervals (Plotkin et al., 2021). This preferential activation of fast-twitch fibers contributes to greater strength gains (Potteiger et al., 1999), crucial for improving jump height. Thus, the unique biomechanical demands and neuromuscular adaptations induced by JIT render it a more effective modality for enhancing JMJ performance compared to running HIIT.

Despite the innovative nature of our study, it is not without limitations. One limitation relates to the fact that the training load was not quantified, making it impossible to identify the specific load mechanisms underlying the observed adaptations. Additionally, this study was conducted at the youth regional level, where trainability may be higher, thus potentially favoring the introduction of new methods. Therefore, future research should aim to expand into more elite contexts and incorporate monitoring of sessions using internal and external load measures to allow for quantification and establishment of dose-response relationships.

Conclusion

Our study provides evidence regarding the effectiveness of a more specialized conditioning training regimen for enhancing aerobic, anaerobic, and jump performance in aerobic gymnastics athletes. Based on our findings, we advocate for coaches to incorporate JIT sessions into their training routine twice a week. Even brief sessions lasting 4 to 5 minutes can sufficiently stimulate significant improvements after an 8-week period. JIT training holds potential as it closely aligns with the demands of the sport. This approach supports their energy systems and enhances jumping performance, thereby contributing to overall athletic improvement.

Acknowledgements

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References

Abe, T., Kitaoka, Y., Kikuchi, D.M., Takeda, K., Numata, O. and Takemasa, T. (2015) High-intensity interval training-induced metabolic adaptation coupled with an increase in Hif-1α and glycolytic protein expression. *Journal of Applied Physiology* **119**, 1297-1302. https://doi.org/10.1152/japplphysiol.00499.2015

Abuwarda, K., Mansy, M. and Megahed, M. (2024) High-intensity interval training on unstable vs stable surfaces: effects on explosive strength, balance, agility, and Tsukahara vault performance in gymnastics. *Pedagogy of Physical Culture and Sports* **28**, 43-52. https://doi.org/10.15561/26649837.2024.0105

Ache-Dias, J., Dellagrana, R.A., Teixeira, A.S., Dal Pupo, J. and Moro, A.R.P. (2016) Effect of jumping interval training on neuromuscular and physiological parameters: a randomized controlled study. *Applied Physiology, Nutrition, and Metabolism* **41**, 20-25. https://doi.org/10.1139/apnm-2015-0368

Afroundeh, R., Saleh, V., Siahkouhian, M. and Asadi, A. (2020) The effect of an 8-week anaerobic gymnastics training on BDNF, VEGF, and some physiological characteristics in children. *Science of Gymnastics Journal* **12**, 381-394. https://doi.org/10.52165/sgj.12.3.381-394

Aleksandraviciene, R., Zaicenkoviene, K., Stasiule, L. and Stasiulis, A. (2015) Physiological Responses and Energetics of Competitive Group Exercise in Female Aerobic Gymnasts with Different Levels of Performance. *Perceptual and Motor Skills* **120**, 787-803. https://doi.org/10.2466/29.26.PMS.120v15x7

Alves, C.R.R., Borelli, M.T.C., Paineli, V. de S., Azevedo, R. de A., Borelli, C.C.G., Lancha Junior, A.H., Gualano, B and Artioli G. G.. (2015) Development of a Specific Anaerobic Field Test for Aerobic Gymnastics. *Plos One* **10**, e0123115. https://doi.org/10.1371/journal.pone.0123115

Astorino, T.A., Allen, R.P., Roberson, D.W. and Jurancich, M. (2012) Effect of High-Intensity Interval Training on Cardiovascular Function, V̇o2max, and Muscular Force. *Journal of Strength and Conditioning Research* **26**, 138-145. https://doi.org/10.1519/JSC.0b013e318218dd77

Berthon, P., Fellmann, N., Bedu, M., Beaune, B., Dabonneville, M., Coudert, J. and Chamoux, A. (1997) A 5-min running field test as a measurement of maximal aerobic velocity. *European Journal of Applied Physiology* **75**, 233-238. https://doi.org/10.1007/s004210050153

Boullosa, D., Dragutinovic, B., Feuerbacher, J.F., Benítez-Flores, S., Coyle, E.F. and Schumann, M. (2022) Effects of short sprint interval training on aerobic and anaerobic indices: A systematic review and meta-analysis. *Scandinavian Journal of Medicine & Science in Sports* **32**, 810-820. https://doi.org/10.1111/sms.14133

Brandão, L.H.A., Chagas, T.P.N., Vasconcelos, A.B.S., de Oliveira, V.C., Fortes, L. de S., de Almeida, M.B., Netto, R. S. M., Del-Vecchio, F. B., Neto, E. P., Chaves, L. M. S., Jimenez-Pavón, D. and Silva-Grigoletto, M. E. (2020) Physiological and Performance Impacts After Field Supramaximal High-Intensity Interval Training With Different Work-Recovery Duration. *Frontiers in Physiology* **11**. https://doi.org/10.3389/fphys.2020.01075

Buchheit, M. and Laursen, P.B. (2013a) High-intensity interval training, solutions to the programming puzzle: Part II: Anaerobic energy, neuromuscular load, and practical applications. *Sports Medicine* **43**, 927-954. https://doi.org/10.1007/s40279-013-0066-5

Buchheit, M. and Laursen, P.B. (2013b) High-intensity interval training, solutions to the programming puzzle Part I: Cardiopulmonary emphasis. *Sports medicine (Auckland, N.Z.)* **43**, 313-38. https://doi.org/10.1007/s40279-013-0029-x

Callahan, M.J., Parr, E.B., Hawley, J.A. and Camera, D.M. (2021) Can High-Intensity Interval Training Promote Skeletal Muscle Anabolism? *Sports Medicine* **51**, 405-421. https://doi.org/10.1007/s40279-020-01397-3

Chang, S.C., Adami, A., Lin, H.C., Lin, Y.C., Chen, C.P.C., Fu, T.C., Hsu, C. C. and Huang, S. C. (2020) Relationship between maximal incremental and high-intensity interval exercise performance in elite athletes. *Plos One* **15**, e0226313. https://doi.org/10.1371/journal.pone.0226313

Cooper, S.M. (2005) The repeatability and criterion related validity of the 20 m multistage fitness test as a predictor of maximal oxygen uptake in active young men. *British Journal of Sports Medicine* **39**, e19. https://doi.org/10.1136/bjsm.2004.013078

Cuce, G., Oksuzoglu, A.Y. and Atabas, E.G. (2021) The effect of plyometric and tabata training on jump performance, respiratory function parameters on aerobic gymnasts. *Turkish Journal of Sport and Exercise* **23**, 374-383.

Gabriel, B.M. and Zierath, J.R. (2017) The Limits of Exercise Physiology: From Performance to Health. *Cell Metabolism* **25**, 1000-1011. https://doi.org/10.1016/j.cmet.2017.04.018

Gibala, M.J. and McGee, S.L. (2008) Metabolic Adaptations to Short-term High-Intensity Interval Training. *Exercise and Sport Sciences Reviews* **36**, 58-63. https://doi.org/10.1097/JES.0b013e318168ec1f

Haynes, T., Bishop, C., Antrobus, M. and Brazier, J. (2019) The validity and reliability of the My Jump 2 app for measuring the reactive strength index and drop jump performance. *The Journal of Sports Medicine and Physical Fitness* **59**, 253-258. https://doi.org/10.23736/S0022-4707.18.08195-1

Hoshino, D., Kitaoka, Y. and Hatta, H. (2016) High-intensity interval training enhances oxidative capacity and substrate availability in skeletal muscle. *The Journal of Physical Fitness and Sports Medicine* **5**, 13-23. https://doi.org/10.7600/jpfsm.5.13

Khalafi, M., Sakhaei, M.H., Kazeminasab, F., Symonds, M.E. and Rosenkranz, S.K. (2022) The impact of high-intensity interval training on vascular function in adults: A systematic review and meta-analysis. *Frontiers in Cardiovascular Medicine* **9**. https://doi.org/10.3389/fcvm.2022.1046560

Kramer, A., Poppendieker, T. and Gruber, M. (2019) Suitability of jumps as a form of high-intensity interval training: effect of rest duration on oxygen uptake, heart rate and blood lactate. *European Journal of Applied Physiology* **119**, 1149-1156. https://doi.org/10.1007/s00421-019-04105-w

Kyselovičová, O. and Danielová, K. (2012) The functional response to training and competition load in aerobic gymnastics athletes. *Acta facultatis educationis physicae universitatis Comenianae* **52**, 31-36.

Lamošová, A., Kyselovičová, O. and Tomková, P. (2021) Anthropometric and motor changes after one-year aerobic gymnastics training in young gymnasts. *Science of Gymnastics Journal* **13**, 243-251. https://doi.org/10.52165/sgj.13.2.243-251

Léger, L.A., Mercier, D., Gadoury, C. and Lambert, J. (1988) The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences* **6**, 93-101. https://doi.org/10.1080/02640418808729800

Lemminger, A.K., Fiorenza, M., Eibye, K., Bangsbo, J. and Hostrup, M. (2022) High-Intensity Exercise Training Alters the Effect of N-Acetylcysteine on Exercise-Related Muscle Ionic Shifts in Men. *Antioxidants* **12**, 53. https://doi.org/10.3390/antiox12010053

MacInnis, M.J. and Gibala, M.J. (2017) Physiological adaptations to interval training and the role of exercise intensity. *The Journal of Physiology* **595**, 2915-2930. https://doi.org/10.1113/JP273196

McCaulley, G.O., Cormie, P., Cavill, M.J., Nuzzo, J.L., Urbiztondo, Z.G. and McBride, J.M. (2007) Mechanical efficiency during repetitive vertical jumping. *European Journal of Applied Physiology* **101**, 115-123. https://doi.org/10.1007/s00421-007-0480-1

Pengam, M., Amérand, A., Simon, B., Guernec, A., Inizan, M. and Moisan, C. (2021) How do exercise training variables stimulate processes related to mitochondrial biogenesis in slow and fast trout muscle fibres? *Experimental Physiology* **106**, 938-957. https://doi.org/10.1113/EP089231

Plotkin, D.L., Roberts, M.D., Haun, C.T. and Schoenfeld, B.J. (2021) Muscle Fiber Type Transitions with Exercise Training: Shifting Perspectives. *Sports* **9**, 127.
, https://doi.org/10.3390/sports9090127
Potteiger, J.A., Lockwood, R.H., Haub, M.D., Dolezal, B.A., Almuzaini, K.S., Schroeder, J.M. and Zebas, C. J. (1999) Muscle power and fiber characteristics following 8 weeks of plyometric training. *The Journal of Strength & Conditioning Research* **13**, 275-279. https://doi.org/10.1519/00124278-199908000-00016
Puiu, M. and Dragomir, A. (2020) Neuromuscular and physiological assessment during a vertical jumping test in aerobic gymnastics. *Broad Research in Artificial Intelligence and Neuroscience* **11**, 156-166. https://doi.org/10.18662/brain/11.4Sup1/162
Rosenblat, M.A., Granata, C. and Thomas, S.G. (2022) Effect of Interval Training on the Factors Influencing Maximal Oxygen Consumption: A Systematic Review and Meta-Analysis. *Sports Medicine* **52**, 1329-1352. https://doi.org/10.1007/s40279-021-01624-5
Salse-Batán, J., Varela, S., García-Fresneda, A. and Ayán, C. (2022) Reliability and validity of field-based tests for assessing physical fitness in gymnasts. *Apunts Sports Medicine* **57**, 100397. https://doi.org/10.1016/j.apunsm.2022.100397
Stöggl, T.L. and Björklund, G. (2017) High Intensity Interval Training Leads to Greater Improvements in Acute Heart Rate Recovery and Anaerobic Power as High Volume Low Intensity Training. *Frontiers in Physiology* **8**. https://doi.org/10.3389/fphys.2017.00562
Suchomel, T.J., Lamont, H.S. and Moir, G.L. (2016) Understanding Vertical Jump Potentiation: A Deterministic Model. *Sports Medicine* **46**, 809-828. https://doi.org/10.1007/s40279-015-0466-9
Venegas-Carro, M., Herring, J.T., Riehle, S. and Kramer, A. (2023) Jumping vs. running: Effects of exercise modality on aerobic capacity and neuromuscular performance after a six-week high-intensity interval training. *Plos One* **18**, e0281737. https://doi.org/10.1371/journal.pone.0281737
Wade, L., Lichtwark, G. and Farris, D.J. (2018) Movement Strategies for Countermovement Jumping are Potentially Influenced by Elastic Energy Stored and Released from Tendons. *Scientific Reports* **8**, 2300. https://doi.org/10.1038/s41598-018-20387-0

Key points

- Jumping Interval Training (JIT) proves significantly more effective than high-intensity interval running (HIIT) in enhancing the jumping performance of female gymnasts.
- Introducing both JIT and HIIT sessions, each lasting 4 to 5 minutes, twice a week over 8 weeks, significantly enhances specific anaerobic performance in aerobic gymnastics athletes, along with improving aerobic capacity.

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