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ORIGINAL

EFFECTS OF DIFFERENT INTENSITY JUMP ROPE TRAINING ON HEALTH-RELATED PHYSICAL FITNESS IN PHYSICAL EDUCATION: A COMPARATIVE STUDY BASED ON CURRICULUM IMPLEMENTATION

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ABSTRACT

Background: The decline in adolescent health-related physical fitness has become a global concern. School physical education programs play a crucial role in enhancing physical fitness and promoting students' overall health. **Objective:** This study aims to compare the effects of high-intensity interval jump rope training (High-Intensity Interval Training-Jump Rope, HIIT-JR) and moderate-intensity continuous jump rope training (Moderate-Intensity Continuous Training-Jump Rope, MICT-JR) on health-related physical fitness in adolescents, providing empirical evidence for refining school physical education curricula**. Methods:** A randomized controlled trial was conducted with 120 high school students, who were randomly assigned to the HIIT-JR group, the MICT-JR group, or an unstructured activity control group (FT). The intervention lasted 12 weeks within the framework of school physical education. The HIIT-JR group performed 1-minute high-intensity jump rope exercises (75%–90% of maximum heart rate), alternating with 1-minute rest intervals, for a total of 11 rounds per session. The MICT-JR group performed continuous moderate-intensity jump rope exercises (55%–74% of maximum heart rate) for 11 minutes per session. Health-related physical fitness was assessed using the 20-meter shuttle run (cardiorespiratory endurance), standing long jump (muscular strength), sit-ups (muscular endurance), sit-and-reach test (flexibility), and body mass index (BMI; body composition). Data were analyzed using SPSS 23.0, with two-way repeated measures ANOVA and correlation analysis used to evaluate training effects. **Results:** Both HIIT-JR and MICT-JR effectively improved health-related physical fitness, though their effects differed across various fitness components. Cardiorespiratory endurance: The HIIT-JR group exhibited rapid improvements within the first 6 weeks ($p < 0.01$), whereas the MICT-JR group showed more gradual gains, primarily between Weeks 6 and 12 ($p < 0.05$). Muscular strength: The HIIT-JR group demonstrated significant improvements in standing long jump performance after 6 weeks ($p < 0.01$), while the MICT-JR group showed minimal changes ($p > 0.05$).Muscular endurance: The MICT-JR group exhibited significant improvements in sit-up performance after 12 weeks ($p < 0.01$), whereas no significant changes were observed in the HIIT-JR group ($p > 0.05$).Flexibility: Both training groups showed slight improvements, but the differences were not statistically significant compared to the control group ($p > 0.05$).BMI: The MICT-JR group experienced a significant reduction in BMI after 12 weeks ($p < 0.01$), whereas no significant changes in body weight regulation were detected in the HIIT-JR group ($p > 0.05$). **Conclusion:** Jump rope training of different intensities has varied effects on different components of health-related physical fitness. HIIT-JR leads to faster improvements in cardiorespiratory endurance and muscular strength, while MICT-JR is more effective for enhancing muscular endurance and reducing BMI. A structured integration of both training modalities into physical education programs, customized according to students' individual fitness profiles, may optimize adolescent fitness outcomes and long-term health benefits.

KEYWORDS: Adolescents; Health-Related Physical Fitness; High-Intensity Interval Jump Rope Training (HIIT-JR); Moderate-Intensity Continuous Jump Rope Training (MICT-JR); School Physical Education; Physical Fitness Training

1. INTRODUCTION

The required sample size was determined using G*Power 3.1.9.2, with a medium effect size (0.26). Given an α level of 0.05 and an expected statistical power (1-β) of 0.80, the minimum required sample size was calculated to be 26 participants (Cleophas & Zwinderman, 2016). To account for potential sample attrition, statistical power considerations, and the requirements of the experimental design, researchers selected three high schools from peri-urban areas of Xi'an, Shaanxi Province, China. These schools were randomly assigned to the HIIT-JR, MICT-JR, or control group (Bakker et al., 2020). Each school recruited 40 students, ensuring a balanced distribution in terms of gender, grade level, executive function, and physical activity levels, resulting in a total of 120 non-athlete students (Table 1). Before the experiment, all participants and their guardians provided written informed consent after receiving a detailed explanation of the study's objectives, training protocols, and potential risks and benefits. Inclusion Criteria: (1) No participation in systematic sports training in the past six months；（2）No medical or psychological conditions that could affect executive function or physical performance; （3）No history of severe sports injuries or musculoskeletal disorders. Exclusion Criteria: （1）Inability to continue participation due to illness or accidental injury during the experiment; （2）Absence from more than 20% of the training sessions during the intervention period; （3）Refusal to provide complete data or voluntary withdrawal from the study.

2. Materials and Methods

This study adhered to the ethical guidelines outlined in the Declaration of Helsinki (2013) (Ashcroft, 2008)and was approved by the Ethics Committee of the UKM Sports Science Society, in compliance with its ethical regulations. Before participation, all subjects and their parents received a comprehensive briefing on the study's objectives and procedures, after which written informed consent was obtained.

2.1 Participants

The required sample size was determined using G*Power 3.1.9.2, with a medium effect size (0.26). Given an α level of 0.05 and an expected statistical power (1-β) of 0.80, the minimum required sample size was calculated to be 26 participants (Cleophas & Zwinderman, 2016). To account for potential sample attrition, statistical power considerations, and the requirements of the experimental design, researchers selected three high schools from peri-urban areas of Xi'an, Shaanxi Province, China (Barrio et al., 2023; Bornath & Kenno, 2022). These schools were randomly assigned to the HIIT-JR, MICT-JR, or control group. Each school recruited 40 students, ensuring a balanced distribution in terms of gender, grade level, executive function, and physical activity levels, resulting in a total of 120 non-athlete students (Table 1). Before the experiment, all participants and their guardians provided written informed consent after receiving a detailed explanation of the study's objectives, training protocols, and potential risks and benefits. Inclusion Criteria: (1) No participation in systematic sports training in the past six months;（2）No medical or psychological conditions that could affect executive function or physical performance; （3）No history of severe sports injuries or musculoskeletal disorders. Exclusion Criteria: （1）Inability to continue participation due to illness or accidental injury during the experiment; （2）Absence from more than 20% of the training sessions during the intervention period; （3）Refusal to provide complete data or voluntary withdrawal from the study.

Table 1(a): Descriptive Characteristics of Participants in the Three Experimental Groups

VARIABLES	HII-JRT (N=40)	MIIC-JRT (N=40)	CONTROL (N=40)	ANOVA TEST
AGE	17.32±0.37	17.18±0.46	17.13±0.46	F= 2.13, p = 0.123
HEIGHT	165.60 ± 2.21	164.95 ± 2.24	165.86 ± 2.18	F= 1.80, p = 0.169

Table 1(b): Descriptive Characteristics of Participants in the Three Experimental Groups

VARIABLES	HII-JRT (N=40)	MIIC-JRT (N=40)	CONTROL (N=40)	ANOVA TEST
WEIGHT	63.10 ± 2.22	64.00 ± 2.62	62.91 ± 2.91	F= 2.20, p = 0.140
BMI	22.93 ± 2.19	22.17 ± 2.04	23.06 ± 1.92	F= 0.45, p = 0.638
PHYSICAL ACTIVITY	19.55 ± 5.24	20.75 ± 6.27	20.27 ± 5.50	F= 0.45, p = 0.638

2.2 Jump Rope Cadence Test

Prior to the experiment, researchers measured participants' maximal heart rate (HRmax) and resting heart rate (RHR) using a graded exercise test (GXT). Based on the predefined high-intensity heart rate range (75–90% HRmax) and moderate-intensity heart rate range (55–74% HRmax) in this study, each participant's heart rate reserve (HRR) was calculated to determine their target heart rate (THR) range. Based on the calculated THR range, researchers conducted three 1-minute double-foot jump rope cadence tests for each participant in the HIIT-JR and MICT-JR groups on alternate days. The average cadence from these three trials was calculated, and a common cadence range was identified across participants. The mean jump rope cadence within this range was then designated as the target cadence for all intervention sessions. To ensure compliance with exercise intensity targets, researchers closely monitored participants' cadence-based jump rope pacing while paying particular attention to critical individuals (participants whose cadence fell within the common range) to track fluctuations in heart rate response. This ensured that all participants adhered to the prescribed exercise intensity levels. The measured jump rope cadence outcomes were as follows: （1）HIIT-JR experimental group: 71 jumps per minute (bpm) (Figure 1)；（2）MICT experimental group: 132 jumps per minute (bpm) (Figure 2). Real-time heart rate and perceived exertion levels (RPE) were continuously monitored using a Polar H10 heart rate strap, with RPE evaluations conducted in accordance with the American College of Sports Medicine (ACSM) guidelines

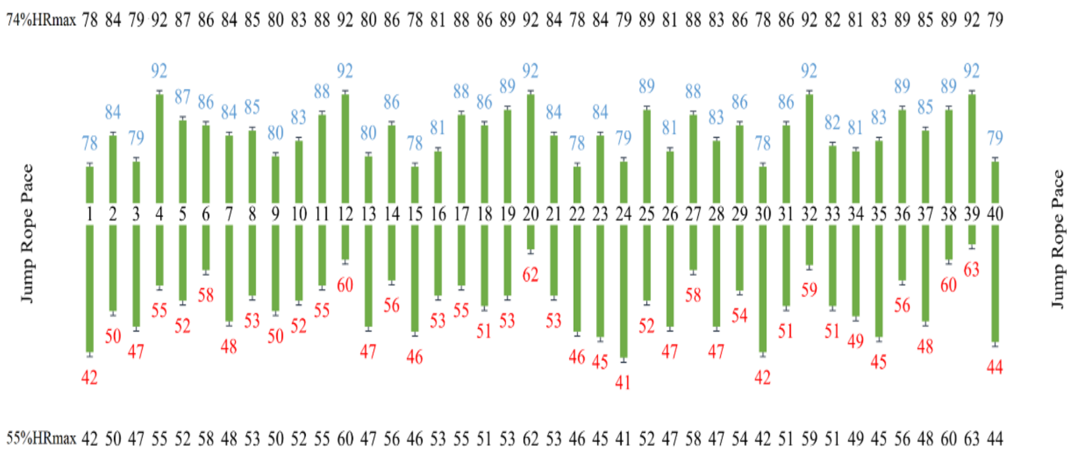

Figure 1: HII-JR One-Minute Jump Rope Pace Test

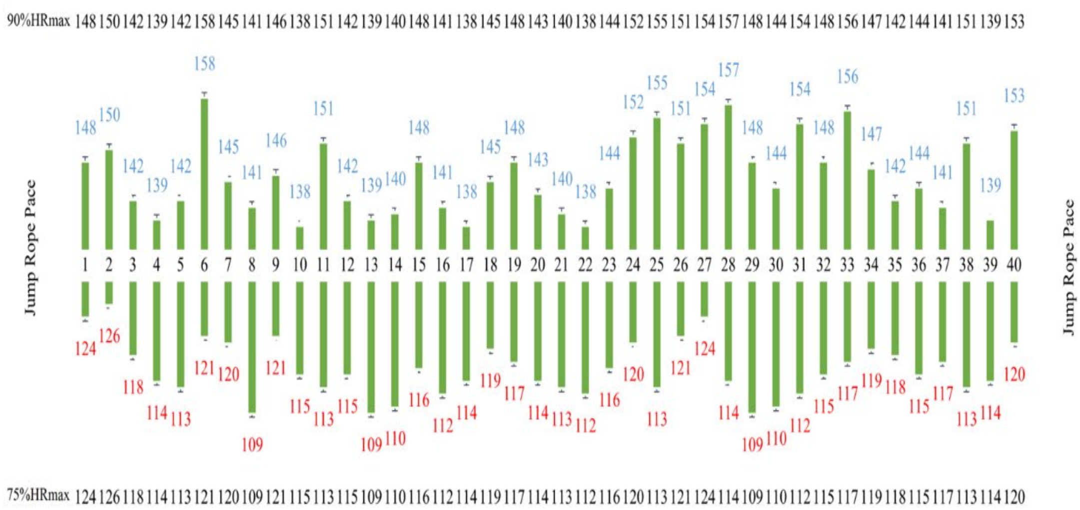

Figure 2: MIIC-JR One-Minute Jump Rope Pace Test

2.3 Health-Related Physical Fitness Assessment

2.3.1 Body Mass Index (BMI) Assessment

This study employed the FITPRO D-1 body composition analyzer, a domestically manufactured device in China, to measure Body Mass Index (BMI). To ensure precise and reliable measurements, strict control over experimental conditions and standardized participant preparation were implemented. Assessments were conducted in a temperature-controlled environment (20–25°C) to minimize external environmental variability that could affect measurement outcomes. The device was positioned on a stable, level surface to eliminate any potential tilting effects that could compromise the accuracy of bioelectrical impedance measurements. Participants followed these standardized pre-measurement protocols to ensure accuracy: （1）Avoid vigorous exercise within 1 hour before the test to prevent physical activity from influencing body composition data. （2）Refrain from eating for 2–3 hours prior to the assessment.（3）Empty the bladder before measurement. （4）Remove all metallic accessories and electronic devices to prevent interference with bioelectrical impedance measurements. During the assessment, participants removed their shoes and socks, positioned their heels against the electrode plate markers, and firmly grasped the device handles to ensure proper contact with the analyzer. Before initiating the measurement, the experimenter verified that the device was level and that the participant's posture was correctly aligned. Participants were required to remain still and maintain normal breathing throughout the assessment. To minimize visual fatigue, they were advised to avoid prolonged direct eye contact with the display screen.

Following the assessment, the device generated data on muscle mass, fat mass, BMI, and body water content, all of which were systematically recorded for subsequent analysis (Kyle et al., 2004). According to the World Health Organization (WHO) BMI classification standards for school-aged children and adolescents (ages 5–19) (Lee, 2008), participants were categorized into the following weight status groups: （1）Underweight: BMI below the 5th percentile for age and sex. （2）Normal weight: BMI between the 5th and 85th percentiles for age and sex. （3）Overweight: BMI between the 85th and 97th percentiles for age and sex. （4）Obese: BMI above the 97th percentile for age and sex. BMI classification provides a standardized framework for assessing adolescent weight status and its potential health implications, facilitating early identification of individuals at risk for weight-related health concerns

2.3.2 Cardiorespiratory Endurance Test

The 20-Meter Shuttle Run Test (Beep Test) is a widely recognized intermittent fitness test used in sports science and physical performance evaluation to assess cardiorespiratory endurance. This study employed this method to measure participants' aerobic capacity and endurance levels. A flat and firm testing area was selected to ensure an unobstructed running track. A 20-meter straight track was accurately measured using a measuring tape or measuring wheel, with highly visible markers placed at both ends. The audio equipment was tested to verify that the pre-recorded beep sound files were clear and uninterrupted, and a backup stopwatch or timer was prepared in case of equipment malfunction. Before testing, participants completed a structured 10–15-minute warm-up session, which included light jogging and dynamic stretching to prepare the body for exercise and mitigate injury risk. The test administrator provided a brief overview of the test rules, emphasizing that upon hearing each beep, participants must run from one end of the track to the other, ensuring they cross the designated line before the next beep sounds. As the test progressed, the beep frequency gradually increased, requiring participants to incrementally accelerate their running pace to keep up with the cadence. Throughout the test, participants were advised to maintain steady breathing and proper running posture. If a participant failed to reach the designated line between two consecutive beeps, the administrator recorded the last successfully completed stage and the total number of shuttles completed. At the conclusion of the test, administrators systematically recorded each participant's performance, including the highest successfully completed stage and the total number of shuttles completed, ensuring data integrity and completeness. Participants then engaged in a 5–10-minute cool-down routine (e.g., walking and static stretching) to facilitate gradual recovery and reduce the risk of delayed-onset muscle soreness (DOMS). Upon test completion, administrators provided immediate feedback, explaining individual test results, assessing cardiorespiratory endurance levels, and offering personalized training recommendations or health guidance as needed. The primary equipment for the test included: （1）Measuring Tools: A measuring tape or measuring wheel to ensure precise track length measurement, minimizing potential errors. （2）Marking Tools: Cones or other high-visibility markers to define the 20-meter track boundaries. （3）Audio Equipment: A pre-recorded beep sound file, structured to increase in cadence at standardized intervals throughout the test. （4）Timing Devices: A backup timer or stopwatch to ensure accurate data recording in the event of audio equipment failure. （5）Recording Tools: Paper or electronic spreadsheets for systematically documenting each participant’s test results, including the highest completed stage and total shuttle count, ensuring data accuracy and scientific reliability. This test can be conducted indoors in a controlled low-wind environment or outdoors on a flat, wind-free surface to minimize environmental variability and maintain test consistency. To prevent muscle strains or other exercise-induced injuries, participants must complete an appropriate warm-up routine before testing. Post-test data will be systematically organized and analyzed to uphold scientific rigor and ensure the reliability of findings. The Beep Test remains a well-established method for evaluating aerobic capacity and endurance performance, providing valuable insights for training optimization and the development of physical education curricula.

2.3.3 Muscular Endurance Test

This study assessed muscular endurance using the sit-up test, a widely utilized method in physical education and fitness training to evaluate and enhance endurance performance in both athletes and the general population. The test employed a YS810 digital stopwatch and a QMI metronome, with performance assessed by the total number of correctly executed sit-ups within a 1-minute period. Before testing, the testing area was cleared and leveled, and yoga mats or gymnastics mats were placed on the floor to provide cushioning and minimize the risk of injury. Participants were required to wear loose, comfortable sportswear and remove any items from their pockets or accessories that might hinder movement. Additionally, they engaged in a structured warm-up routine focusing on the abdominal and lower back muscles to optimize performance and prevent injuries. The test administrators ensured that all participants utilized standardized equipment, including timing devices and yoga mats, to maintain consistency and measurement reliability. During the test, participants lay supine on the yoga mat, with their legs naturally apart, knees bent at a 90-degree angle, and hands crossed behind their heads. A test assistant gently stabilized the participant’s ankles to secure the lower body. At the "start" command, the test administrator activated the stopwatch, recording the number of valid sit-ups completed within 1 minute. A repetition was considered valid only if the participant's elbows made direct contact with or extended beyond the knees. If the elbows failed to touch the knees, the repetition was not included in the final score. The total number of correctly executed sit-ups was recorded, rounded to the nearest whole number. Upon test completion, participants performed full-body stretching and targeted relaxation exercises for the abdominal and lower back muscles, facilitating muscle recovery and minimizing post-exercise discomfort. The test administrators systematically documented the total sit-up count, compiled the data for analysis, and ensured proper maintenance of the testing equipment. This assessment provides valuable insights into core muscular endurance, which is essential for overall physical fitness and athletic performance.

2.3.4 Flexibility Test

This study employed the Seated Forward Flexion Test to evaluate participants' flexibility, particularly in the lower back and hamstrings. This test is a widely recognized and standardized assessment tool used for evaluating flexibility and musculoskeletal function. The required equipment included: （1） A standard testing box or a ruler with centimetre markings to ensure precise measurement of forward reach distance. （2）A non-slip testing mat or a firm, level surface to maintain participant stability. （3）A recording sheet for systematic data collection and analysis. Participants wore loose, comfortable clothing to allow free movement and completed a structured warm-up routine, focusing on lower back and hamstring stretches to optimize flexibility performance and mitigate the likelihood of exercise-induced injuries. During the test, participants sat in front of the measuring box, with their ankles positioned at a 90-degree angle, feet together and extended forward, and toes aligned with the 0 cm mark. They extended their arms forward, palms facing downward, ensuring that their knees remained fully straightened throughout the movement. Participants then slowly leaned forward, using their fingertips to push the measurement scale forward as far as possible, maintaining the stretched position for approximately 2 seconds. The test administrator recorded the measurement, with: （1）Positive values recorded when the measurement exceeded the 0 cm mark. （2）Negative values recorded when the measurement fell short of the 0 cm mark. Each participant completed three trials, and the final score was derived from the mean of these measurements, recorded to one decimal place in centimetres.

The Seated Forward Flexion Test is a valuable and widely utilized assessment for flexibility and overall fitness. The use of standardized testing procedures ensures measurement accuracy and comparability across participants. A structured warm-up routine enhances test performance while minimizing the risk of exercise-related injuries. Additionally, averaging the three recorded measurements enhances data reliability and scientific validity, ensuring that the test results are stable and representative of actual flexibility levels. As a key indicator of musculoskeletal health, flexibility is essential for physical function, injury prevention, and athletic performance, making this test a critical tool in fitness assessment and sports training.

2.3.5 Muscular Strength Test

This study utilized the standing long jump test to evaluate participants' lower-body muscular strength. Recognized for its efficiency and simplicity, this test is widely employed in physical fitness assessments. Participants were required to jump forward as far as possible from a standing position without external assistance. To ensure fairness and measurement accuracy, the standing long jump test was conducted in a sandpit level with the ground, and a measuring tape was used to determine jump distances. Researchers employed standardized measuring instruments, ensuring that all equipment was properly calibrated and inspected to maintain precision and consistency in measurements. Each participant completed three jump trials, with approximately 10-minute rest intervals between attempts to allow for full recovery and minimize fatigue-related effects on performance. The final performance score was determined by averaging the distances of the three jumps, recorded in centimeters to one decimal place. This approach minimized random variations, enhanced test reliability and validity, and provided a more precise representation of participants' actual jumping capacity. To standardize test conditions, researchers prepared the sandpit by loosening the surface with a shovel and ensuring an even, depression-free landing area using a leveling tool. The take-off line was positioned at least 30 cm from the near edge of the sandpit and was clearly marked with high-visibility indicators. Participants stood behind the take-off line with their feet naturally apart and gaze fixed forward. After fully swinging their arms backward and relaxing their posture, they executed a forceful bilateral push-off, synchronizing an upward and forward arm swing to maximize propulsion. participants lowered their center of gravity and shifted their weight forward, bringing their knees in to maintain balance and prevent backward instability. Following each jump, researchers recorded the vertical distance from the rear edge of the take-off line to the participant's furthest landing point, ensuring a transparent and standardized assessment process. To uphold measurement consistency, researchers systematically re-leveled the sandpit using a leveling instrument after each trial. Upon completion of the test, participants performed recovery exercises, including slow walking and static stretching, to reduce muscle tension, improve blood circulation, and minimize the risk of delayed-onset muscle soreness (DOMS).As a widely recognized field test for explosive lower-body strength, the standing long jump provides valuable insights into athletic performance and neuromuscular power, making it a key assessment tool in physical education and sports training

2.4 Experimental Intervention Procedure

This study employed a 3 (Group: HIIT-JR, MICT-JR, and FT) × 3 (Time:

Pre-test (T0), Mid-test (T1), Post-test (T2)) mixed-design framework to examine the effects of different jump rope training intensities on executive function over time. The dependent variables included response time (RT) measurements from the inhibitory function, working memory, and cognitive flexibility tests. Before each test session, participants completed 20 practice trials to ensure familiarity with the task. A minimum accuracy rate of 85% was required before advancing to formal testing. Executive function assessments were conducted at the following time points：T0 = Week 1 (Pre-intervention) ，T1 = Week 6 (Mid-intervention) ，T2 = Week 12 (Post-intervention) ，To monitor exercise intensity, perceived exertion levels (RPE) were recorded before and after each session, and the mean RPE was computed. The intervention spanned 12 weeks, with participants training three times per week, each session lasting approximately 17 minutes. Figure 3 presents a detailed overview of the intervention protocol.

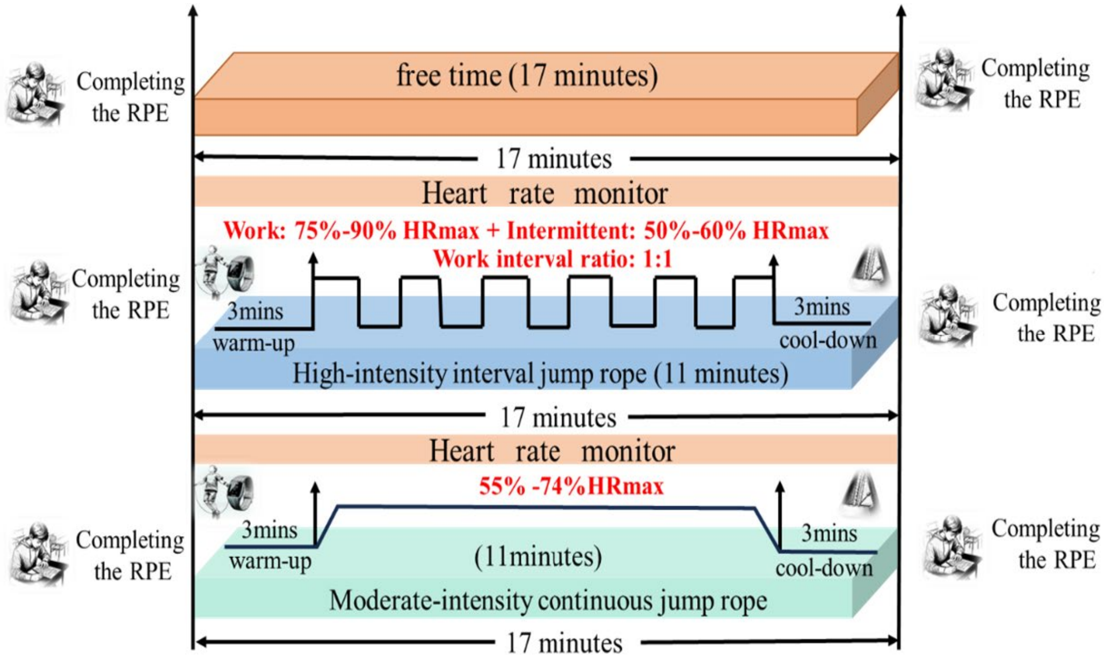

Figure 3: Experimental Program

2.5 Statistical Analysis

Repeated measures analysis of variance (RM ANOVA) was employed to analyze response time (RT) and response accuracy. Mauchly's sphericity test was used to evaluate sphericity, and the Greenhouse–Geisser correction was applied when sphericity assumptions were violated (Ma et al., 2012). The Shapiro–Wilk test was conducted to assess whether the data followed a normal distribution. Following normality assessment, post hoc comparisons were conducted using paired sample t-tests with Bonferroni adjustment (Potvin, 1996)。

3. Results

3.1 Effects of Different Jump Rope Interventions on Body Mass Index (BMI)

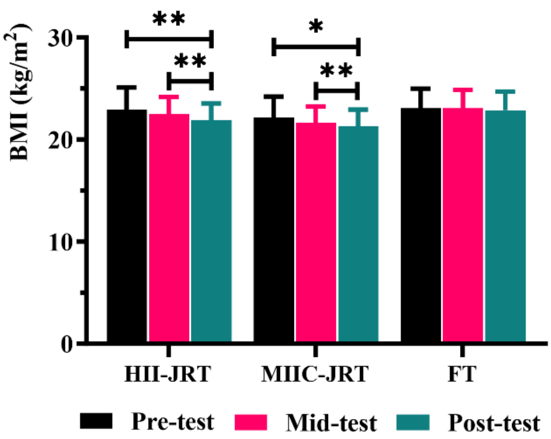

Figure 4: Within-Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Body Composition (BMI)

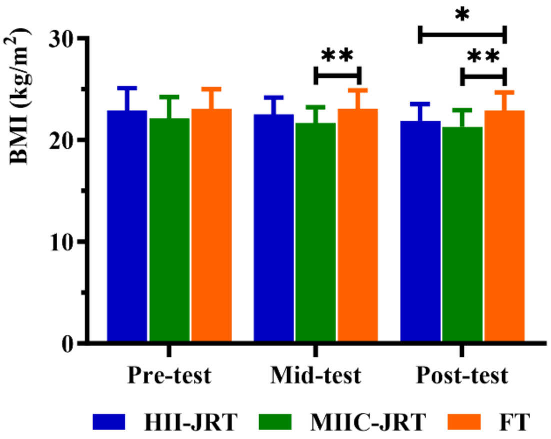

Figure 5: Within Between -Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Body Composition (BMI)

Repeated measures ANOVA results (as shown in Figure 4) revealed that, in the high-intensity interval jump rope (HIIT-JR) group, pre-test BMI was higher than mid-test BMI, though the difference was not statistically significant ($p = 0.370$), with a mean difference (± standard error) of 0.418 ± 0.269 kg/m². However, pre-test BMI was significantly higher than post-test BMI ($p = 0.002$), with a mean difference (± standard error) of 1.030 ± 0.289 kg/m². Furthermore, mid-test BMI was significantly higher than post-test BMI ($p < 0.001$), with a mean difference (± standard error) of 0.612 ± 0.101 kg/m². In the moderate-intensity continuous jump rope (MICT-JR) group, pre-test BMI was higher than mid-test BMI, though this difference did not reach statistical significance ($p = 0.209$), with a mean difference (± standard error) of 0.492 ± 0.269 kg/m². However, pre-test BMI was significantly higher than post-test BMI ($p = 0.010$), with a mean difference (± standard error) of 0.867 ± 0.289 kg/m². Moreover, mid-test BMI was significantly higher than post-test BMI ($p < 0.001$), with a mean difference (± standard error) of 0.375 ± 0.101 kg/m².

As illustrated in Figure 5, at mid-test, the BMI of the HIIT-JR group was higher than that of the MICT-JR group, though the difference was not statistically significant ($p = 0.080$), with a mean difference (± standard error) of 0.842 ± 0.375 kg/m². Compared to the free activity (FT) group, the HIIT-JR group exhibited a slightly lower BMI, but this difference was not significant ($p = 0.389$), with a mean difference (± standard error) of -0.573 ± 0.375 kg/m². Conversely, the BMI of the MICT-JR group was significantly lower than that of the FT group ($p < 0.001$), with a mean difference (± standard error) of -1.415 ± 0.375 kg/m². In the post-test comparison, BMI in the HIIT-JR group remained higher than in the MICT-JR group, but the difference was not statistically significant (p = 0.340), with a mean difference (± standard error) of 0.605 ± 0.379 kg/m². However, compared to the FT group, BMI in the HIIT-JR group was significantly lower (p = 0.031), with a mean difference (± standard error) of -0.988 ± 0.379 kg/m². Additionally, BMI in the MICT-JR group was also significantly lower than in the FT group (p < 0.001), with a mean difference (± standard error) of -1.593 ± 0.379 kg/m². These findings suggest that while both jump rope interventions contributed to BMI reductions, MICT-JR demonstrated a more pronounced effect compared to HIIT-JR and FT, indicating potential benefits for long-term weight management.

3.2 Effects of Different Jump Rope Interventions on Cardiorespiratory Endurance

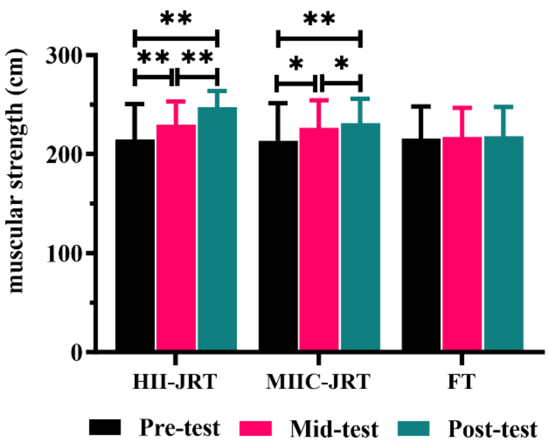

Figure 6: Within-Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Muscular Strength

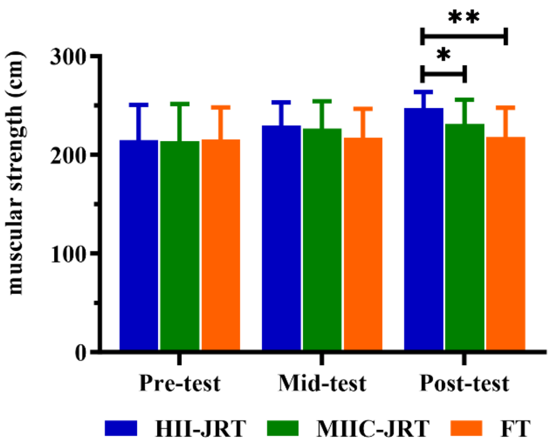

Figure 7: Between -Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Muscular Strength

Repeated measures ANOVA results (as shown in Figure 6) revealed that, in the high-intensity interval jump rope (HIIT-JR) group, muscular strength at pre-test was significantly lower than at mid-test (p = 0.011), with a mean difference (± standard error) of -14.312 ± 4.850 cm. Additionally, muscular strength at pre-test was significantly lower than at post-test (p < 0.001), with a mean difference (± standard error) of -32.023 ± 5.210 cm. Furthermore, muscular strength at mid-test was significantly lower than at post-test (p < 0.001), with a mean difference (± standard error) of -17.710 ± 1.708 cm. In the moderate-intensity continuous jump rope (MICT-JR) group, muscular strength at pre-test was also significantly lower than at mid-test (p = 0.024), with a mean difference (± standard error) of -13.065 ± 4.850 cm. Additionally, muscular strength at pre-test was significantly lower than at post-test (p = 0.003), with a mean difference (± standard error) of -17.527 ± 5.210 cm. Moreover, muscular strength at mid-test was significantly lower than at post-test (p = 0.030), with a mean difference (± standard error) of -4.463 ± 1.708 cm.

As shown in Figure 7, a simple effects analysis was conducted at predetermined time points, adjusting for time as a covariate to assess group differences. The results indicated that, following the intervention, muscular strength in the HIIT-JR group was significantly greater than in the MICT-JR group (p = 0.012), with a mean difference (± standard error) of 15.975 ± 5.438 cm. Additionally, the HIIT-JR group exhibited significantly higher muscular strength than the free activity (FT) group (p < 0.001), with a mean difference (± standard error) of 29.195 ± 5.438 cm. In contrast, although muscular strength in the MICT-JR group exceeded that of the FT group, the difference did not reach statistical significance (p = 0.05), with a mean difference (± standard error) of 13.220 ± 5.438 cm. These findings suggest that HIIT-JR is more effective in enhancing muscular strength compared to MICT-JR and FT, highlighting its potential for improving lower-body power in physical training programs.

3.3 Effects of Different Jump Rope Interventions on Muscular Endurance

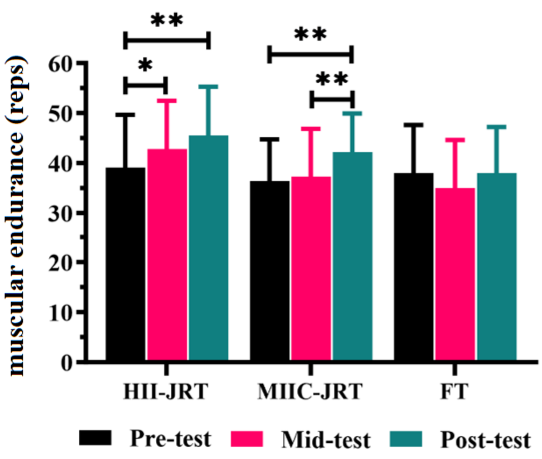

Figure 8: Within-Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Muscular Endurance

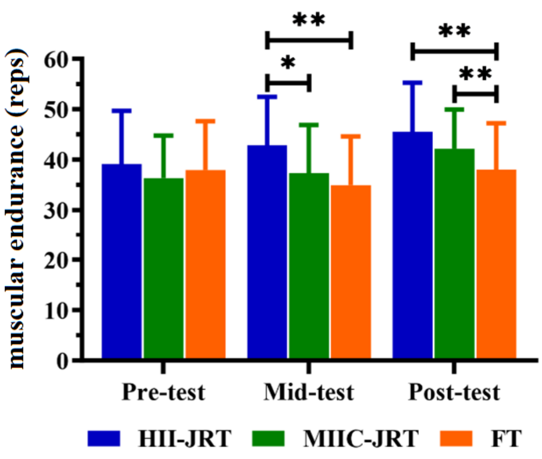

Figure 9: Between-Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Muscular Endurance

Repeated measures ANOVA results (as shown in Figure 8) revealed that, in the high-intensity interval jump rope (HIIT-JR) group, pre-test muscular endurance was significantly lower than mid-test values (p = 0.033), with a mean difference (± standard error) of -3.675 ± 1.424 repetitions. Additionally, pre-test muscular endurance was also significantly lower than post-test values (p < 0.001), with a mean difference (± standard error) of -6.350 ± 0.553 repetitions. Although mid-test muscular endurance was higher than post-test values, the difference was not statistically significant (p = 0.170), with a mean difference (± standard error) of -2.675 ± 1.389 repetitions. In the moderate-intensity continuous jump rope (MICT-JR) group, pre-test muscular endurance was lower than mid-test values, but this difference was not statistically significant (p > 0.001), with a mean difference (± standard error) of -0.950 ± 1.424 repetitions. However, pre-test muscular endurance was significantly lower than post-test values (p < 0.001), with a mean difference (± standard error) of -5.800

± 0.553 repetitions. Moreover, mid-test muscular endurance was significantly lower than post-test values (p = 0.002), with a mean difference (± standard error) of -4.850 ± 1.389 repetitions.

As shown in Figure 9, a simple effects analysis was conducted at predetermined time points, adjusting for time as a covariate to examine intergroup differences. The results indicated that, at mid-test, muscular endurance in the HIIT-JR group was significantly greater than in the MICT-JR group (p = 0.036), with a mean difference (± standard error) of 5.500 ± 2.152 repetitions. Additionally, muscular endurance in the HIIT-JR group was significantly higher than in the free activity (FT) group (p = 0.001), with a mean difference (± standard error) of 7.850 ± 2.152 repetitions. In contrast, although the MICT-JR group demonstrated greater muscular endurance than the FT group, this difference was not statistically significant (p = 0.831), with a mean difference (± standard error) of 2.350 ± 2.152 repetitions. In the post-test comparison, muscular endurance in the HIIT-JR group was higher than in the MICT-JR group, but the difference was not statistically significant (p = 0.299), with a mean difference (± standard error) of 3.325 ± 2.004 repetitions. However, post-test muscular endurance in the HIIT-JR group was significantly higher than in the FT group (p < 0.001), with a mean difference (± standard error) of 7.500 ± 2.004 repetitions. Additionally, muscular endurance in the MICT-JR group was higher than in the FT group, but the difference was not statistically significant (p = 0.118), with a mean difference (± standard error) of 4.175 ± 2.004 repetitions. These findings suggest that HIIT-JR is more effective in improving muscular endurance compared to MICT-JR and FT, highlighting its potential for enhancing endurance performance in structured training programs.

3.4 Effects of Different Jump Rope Interventions on Muscular Strength

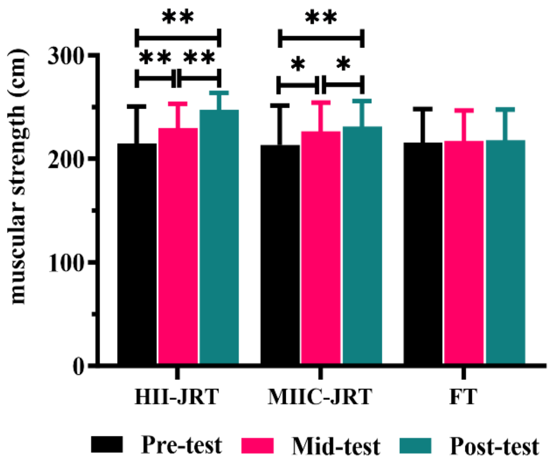

Figure 10: Within-Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Muscular Strength

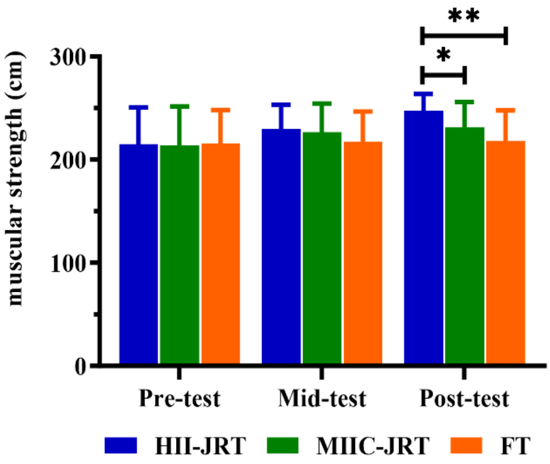

Figure 11: Between -Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Muscular Strength

Repeated measures ANOVA results (as shown in Figure 10) revealed that, in the high-intensity interval jump rope (HIIT-JR) group, muscular strength at pre-test was significantly lower than at mid-test (p = 0.011), with a mean difference (± standard error) of -14.312 ± 4.850 cm. Additionally, muscular strength at pre-test was significantly lower than at post-test (p < 0.001), with a mean difference (± standard error) of -32.023 ± 5.210 cm. Furthermore, mid-test muscular strength was significantly lower than post-test values (p < 0.001), with a mean difference (± standard error) of -17.710 ± 1.708 cm. In the moderate-intensity continuous jump rope (MICT-JR) group, muscular strength at pre-test was also significantly lower than at mid-test (p = 0.024), with a mean difference (± standard error) of -13.065 ± 4.850 cm. Additionally, muscular strength at pre-test was significantly lower than at post-test (p = 0.003), with a mean difference (± standard error) of -17.527 ± 5.210 cm. Moreover, muscular strength at mid-test was significantly lower than at post-test (p = 0.030), with a mean difference (± standard error) of -4.463 ± 1.708 cm.

As shown in Figure 11, a simple effects analysis was performed at fixed time points, controlling for time as a covariate to assess differences between groups. The results indicated that, following the intervention, post-test muscular strength in the HIIT-JR group was significantly higher than in the MICT-JR group (p = 0.012), with a mean difference (± standard error) of 15.975 ± 5.438 cm. Furthermore, post-test muscular strength in the HIIT-JR group was significantly greater than in the free activity (FT) group (p < 0.001), with a mean difference (± standard error) of 29.195 ± 5.438 cm. Conversely, although muscular strength in the MICT-JR group was higher than in the FT group, this difference was not statistically significant (p = 0.050), with a mean difference (± standard error) of 13.220 ± 5.438 cm. These findings suggest that HIIT-JR is more effective in enhancing muscular strength compared to MICT-JR and FT, supporting its role in strength-based training interventions.

3.5 Effects of Different Jump Rope Interventions on Flexibility

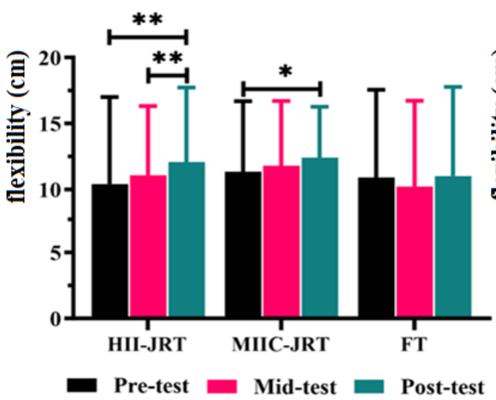

Figure 12: Within-Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Flexibility

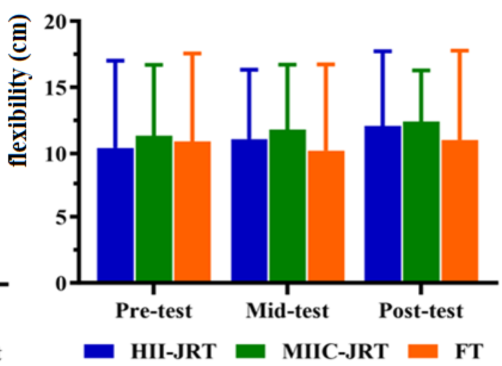

Figure 13: Between-Group Comparisons of the Effects of Different Intensity Jump Rope Protocols on Flexibility

Repeated measures ANOVA results (as shown in Figure 4-13) indicated that, in the high-intensity interval jump rope (HIIT-JR) group, flexibility scores at pre-test were lower than at mid-test; however, this difference was not statistically significant ($p = 0.086$), with a mean difference (± standard error) of -0.652 ± 0.294 cm. In contrast, flexibility at pre-test was significantly lower than at post-test ($p < 0.001$), with a mean difference (± standard error) of -1.650 ± 0.416 cm. Additionally, mid-test flexibility was significantly lower than post-test values ($p = 0.016$), with a mean difference (± standard error) of -0.998 ± 0.350 cm. In the moderate-intensity continuous jump rope (MICT-JR) group, pre-test flexibility scores were lower than at mid-test, but the difference was not statistically significant ($p = 0.362$), with a mean difference (± standard error) of -0.460 ± 0.294 cm. However, flexibility at pre-test was significantly lower than at post-test ($p = 0.032$), with a mean difference (± standard error) of -1.078 ± 0.416 cm. Furthermore, although mid-test flexibility scores were lower than post-test values, this difference was not statistically significant ($p = 0.242$), with a mean difference (± standard error) of -0.617 ± 0.350 cm. These findings suggest that both HIIT-JR and MICT-JR interventions contributed to improvements in flexibility, with HIIT-JR demonstrating a more pronounced effect. This highlights the potential of structured jump rope training for enhancing flexibility in physical education programs.

4. Discussion

This study investigated the effects of high-intensity interval jump rope training (HIIT-JR) and moderate-intensity continuous jump rope training (MICT-JR) in high school physical education by comparing their influence on health-related physical fitness (HRPF). The findings indicate that both training modalities significantly improved BMI, cardiorespiratory endurance, muscular endurance, muscular strength, and flexibility, yet their mechanisms of action and specific effects differed. HIIT-JR demonstrated superior benefits in enhancing muscular strength and endurance, whereas MICT-JR was more effective in BMI regulation and cardiorespiratory fitness enhancement. The free activity (FT) group exhibited significantly lower performance across multiple fitness parameters, further reinforcing the efficacy of jump rope training in improving adolescent HRPF. As a comprehensive measure of physical function, HRPF has been a central focus in physical education practice. Extensive research has shown that regular physical activity contributes to improvements in adolescent HRPF, including reductions in body fat percentage, enhancements in cardiorespiratory function, and gains in muscular strength and endurance. Catley and Tomkinson (Catley & Tomkinson, 2013) found that an 8-week physical education intervention significantly improved cardiorespiratory fitness, muscular fitness, and flexibility in children aged 10–11 years. Similarly, a meta-analysis by Kriemler et al. (Kriemler et al., 2011) reported that physical education programs have a moderate positive effect on HRPF in children and adolescents ($g = 0.35$). Regarding BMI changes, both the

HIIT-JR and MICT-JR groups experienced significant reductions in BMI after 12 weeks of jump rope training, with HIIT-JR exhibiting a more pronounced decrease. This suggests that high-intensity interval jump rope training may be more effective for weight control and fat reduction than moderate-intensity continuous training (Ha et al., 2017). In line with these findings, Christensen et al. (Christensen et al., 1996) examined obese adolescents and reported that a 12-week HIIT program significantly reduced BMI by -3.8 kg/m², surpassing the reduction observed in the MICT group (-2.2 kg/m²). The authors attributed this effect to excess post-exercise oxygen consumption (EPOC) and elevated catecholamine levels associated with high-intensity exercise, which enhance fat mobilization and oxidation (Lunt et al., 2014). Furthermore, given the potential impact of pubertal growth spurts on height changes, future research should adopt more precise body composition assessment techniques (e.g., dual-energy X-ray absorptiometry [DXA]) to elucidate the specific effects of jump rope training on body composition (Mazurek et al., 2016). From the perspective of cardiorespiratory function enhancement, both jump rope training modalities yielded significant improvements, though the HIIT-JR group exhibited a greater enhancement than the MICT-JR group. This indicates that while moderate-intensity aerobic exercise lays the groundwork for cardiovascular fitness, high-intensity training facilitates greater cardiopulmonary adaptation (PK, 2024; Wei & Qiu, 2024). Supporting this notion, Thackray et al. (2013) found that, in healthy adults, HIIT induced greater increases in cardiac output and pulmonary ventilation than MICT, thereby enhancing cardiopulmonary adaptation. Similarly, a meta-analysis by Cao et al. (Cao et al., 2019) reported that in improving maximal oxygen uptake (VO_2max) among adolescents, HIIT had a significantly greater effect size (g = 0.86) compared to MICT (g = 0.52) (DANIEL, 2021). Nonetheless, some researchers warn that excessively frequent or prolonged HIIT sessions may contribute to cumulative fatigue and elevate the risk of exercise-induced injuries. Therefore, when designing jump rope training programs, it is essential to consider students' physical conditions and baseline fitness levels, adhering to a progressive training approach that ensures training intensity while prioritizing safety (Watson et al., 2022) Regarding muscular strength and endurance, both the HIIT-JR and MICT-JR groups exhibited significant improvements, with HIIT-JR showing a more pronounced advantage. This suggests that jump rope training plays a unique role in enhancing muscular function (Miyaguchi et al., 2015). On one hand, jump rope training engages gravitational and ground reaction forces, providing substantial resistance stimuli to lower limb muscles—particularly the quadriceps and gastrocnemius—thereby facilitating muscle hypertrophy and strength development (Orhan, 2013). On the other hand, by increasing the proportion of slow-twitch muscle fibers and mitochondrial density, jump rope training enhances aerobic metabolism efficiency and resistance to fatigue (Trecroci et al., 2015) .Notably, post-training muscular strength was significantly higher in the HIIT-JR group compared to the MICT-JR group, whereas no significant difference was observed between the MICT-JR and FT groups. These findings imply that optimizing exercise intensity, rather than merely increasing exercise volume, may be the key to improving muscle function (Wilkerson et al., 2004) .Future studies should incorporate non-invasive methodologies, such as surface electromyography (sEMG) and near-infrared spectroscopy (NIRS), to elucidate the neuromuscular activation patterns underlying HIIT- and MICT-based jump rope training, thereby refining training protocols. By refining training intensity and leveraging neuromuscular insights, future interventions can maximize the efficacy of jump rope training in physical education and athletic performance (Buchheit et al., 2014; Geidne et al., 2013; Zhao et al., 2023). And MICT-JR groups showed improvements, with the HIIT-JR group exhibiting a more pronounced enhancement. This effect may be attributed to the large-amplitude, high-paced joint movements and muscle stretching involved in jump rope training. A study by Trecroci et al. (Trecroci et al., 2015) on adolescent soccer players found that an 8-week jump rope training program significantly improved lower limb joint mobility, particularly ankle dorsiflexion range. The researchers hypothesized that these benefits stem from enhanced tendon elasticity and improved joint lubrication, which reduce stiffness and adhesion (Catley & Tomkinson, 2013). However, given the heightened plasticity of the musculoskeletal system during puberty, relying solely on jump rope training may not be sufficient for comprehensive flexibility development (Hough, 2021; Karlsen et al., 2017). Future studies should explore hybrid approaches that combine jump rope training with structured stretching regimens, incorporating a range of objective measures (e.g., range of motion [ROM], muscle stiffness) to optimize training effects (Campo et al., 2009). This study employed a rigorous repeated-measures design and a stratified randomization approach, effectively controlling for potential confounding factors such as participants' demographic characteristics and baseline physical fitness levels, thereby enhancing the internal validity of the findings (Ramírez-Campillo et al., 2013). However, due to practical constraints, it was difficult to fully monitor participants' diet and additional physical activities throughout the study period, which may have influenced the accuracy of the results. Additionally, the relatively small sample size, along with the limited age range and regional background of participants, constrains the generalizability of the findings (Slimani et al., 2016).Future investigations should aim to broaden the sample demographic—encompassing varied age groups, genders, and physical profiles—while implementing multi-center, longitudinal randomized controlled trials to generate more robust and externally valid findings (Turgut et al., 2017) . Furthermore, incorporating advanced methodologies—including medical imaging, biochemical profiling, and multidimensional assessments—alongside genetic screening and psychological-behavioral evaluations, will provide deeper insights into the complex mechanisms through which jump rope training influences adolescent physical fitness (García-Hermoso et al., 2019).

In summary, this study confirms that 12 weeks of high-intensity interval jump rope training (HIIT-JR) significantly improves BMI, cardiorespiratory endurance, muscular strength, muscular endurance, and flexibility in high school students, demonstrating greater effectiveness than an equivalent duration of moderate-intensity continuous jump rope training (MICT-JR).Beyond enriching the empirical foundation for adolescent physical fitness enhancement, these findings provide valuable insights for school-based physical education (PE) practices. When designing jump rope training programs, educators should carefully consider students' physical conditions and baseline fitness levels, adhering to a scientifically structured principle of progressive overload to maximize HIIT benefits while ensuring safety. Additionally, integrating jump rope training with other physical fitness activities and sports games, tailoring instruction to students' individual needs, and fostering a positive and engaging exercise experience will not only enhance physical fitness but also help students develop lifelong exercise habits. This student-centered, diversified approach represents a key direction for modern PE curriculum reform.

5. Conclusions

This study examined the effects of high-intensity interval jump rope training (HIIT-JR) and moderate-intensity continuous jump rope training (MICT-JR) on the health-related physical fitness (HRPF) of high school students. The findings indicate that both training modalities effectively improved BMI, cardiorespiratory endurance, muscular endurance, muscular strength, and flexibility, though their mechanisms of action and specific effects differed. HIIT-JR demonstrated greater improvements in muscular strength, muscular endurance, and short-term cardiorespiratory endurance, whereas MICT-JR was more effective for BMI regulation and sustaining long-term cardiorespiratory fitness improvements. Specifically, MICT-JR proved more beneficial for fat reduction, making it ideal for students requiring weight management, while HIIT-JR induced less BMI reduction due to its muscle growth effects. Regarding cardiorespiratory endurance, MICT-JR provided stable, gradual improvements, while HIIT-JR rapidly enhanced maximal oxygen uptake (VO_2max), making it more suitable for students with high aerobic demands. In terms of muscular strength and endurance, HIIT-JR outperformed MICT-JR, highlighting its effectiveness in stimulating fast-twitch muscle fiber adaptation and enhancing short-term athletic performance. Both training methods improved flexibility, though the difference was not statistically significant, suggesting that jump rope training naturally promotes joint mobility, which could be further optimized with additional stretching exercises. These results provide scientific evidence for optimizing school-based physical education (PE) programs, emphasizing the importance of tailoring training approaches based on students' individual fitness needs. Given that this intervention lasted only 12 weeks, future research should explore the long-term effects of jump rope training and incorporate physiological markers to further validate its sustained impact on HRPF. In conclusion, this study confirms that jump rope training plays a significant role in improving adolescent HRPF, offering empirical support for refining PE curricula and promoting structured fitness interventions in schools.

6. Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki and received formal approval from the Ethics Committee of the Sports Science Association at Beijing Sport University (Approval No. 202424H). Written informed consent was obtained from all participants and their legal guardians prior to data collection.

7. Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this study. They have no financial, personal, or institutional relationships that could be perceived as influencing the results or interpretation of the data presented. No competing interests exist among the authors in relation to funding, data ownership, authorship, or affiliations.

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