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ORIGINAL

EFFECTS OF HIGH-INTENSITY INTERVAL AND MODERATE-INTENSITY CONTINUOUS JUMP ROPE TRAINING ON EXECUTIVE FUNCTION ENHANCEMENT IN HIGH SCHOOL PHYSICAL EDUCATION: A TEACHING EXPERIMENT-BASED STUDY

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ABSTRACT

Objective： This study aimed to examine the effects of high-intensity interval jump rope training (HIIT-JR) and moderate-intensity continuous jump rope training (MICT-JR) on executive function in high school students. Specifically, it compared the differential impacts of the two training modalities to inform evidence-based practices in secondary school physical education. **Methods：** A randomized controlled trial was conducted involving 120 high school students aged 16–18 years, who were randomly assigned to one of three groups: HIIT-JR, MICT-JR, or a free activity control group (FT). The intervention lasted 12 weeks, with training sessions conducted three times per week, each lasting 17 minutes. Executive function was assessed at baseline (Week 1), mid-intervention (Week 6), and post-intervention (Week 12) using three cognitive tasks: the Stroop task (inhibitory control), the N-back task (working memory), and the More-Odd Shifting task (cognitive flexibility). A two-way repeated measures ANOVA was employed to examine interaction effects between group and time. **Results:** Both HIIT-JR and MICT-JR significantly improved executive function compared to the control group ($p < 0.01$), although the trajectories of improvement varied by training type. The HIIT-JR group exhibited significant enhancements in inhibitory control and cognitive flexibility as early as Week 6 ($p < 0.01$), while the MICT-JR group showed pronounced gains in working memory by Week 12 ($p < 0.05$). Across all executive function domains, both intervention groups demonstrated faster reaction times and higher accuracy relative to the FT group. **Conclusion:** Jump rope training, whether high-intensity interval or moderate-intensity continuous, is effective in enhancing executive function in adolescents. HIIT-JR is particularly beneficial for achieving rapid, short-term improvements in inhibitory control and cognitive flexibility, whereas MICT-JR supports more stable, long-term gains in working memory. These findings provide actionable insights for incorporating targeted jump rope protocols into school-based physical education curricula.

KEYWORDS: Executive Function, Jump Rope Training, Inhibitory Control, Working Memory, Cognitive Flexibility, Physical Education

1. INTRODUCTION

Executive functions are essential components of higher-order cognitive processing, encompassing core domains such as inhibitory control, working memory, and cognitive flexibility. Functioning as a central regulatory system, executive functions are integral to goal-directed behavior, learning, emotional regulation, and adaptive decision-making in daily life (Gilbert & Burgess, 2008). Among high school students, well-developed executive functions have been consistently associated with enhanced academic achievement, improved self-regulation, and greater resilience in the face of academic and social stressors (Liu et al., 2009). However, the modern educational environment—characterized by prolonged sedentary study routines, elevated academic demands, and limited engagement in physical activity—may impede the typical developmental trajectory of executive functions during adolescence (Wang et al., 2011). These challenges highlight the urgent need for evidence-based intervention strategies aimed at promoting cognitive health and optimizing executive functioning in this population. In recent years, physical activity has emerged as a promising avenue for such interventions, drawing increasing attention from scholars and practitioners in the fields of physical education, cognitive neuroscience, and adolescent development. A growing body of research indicates that physical exercise has a beneficial impact on executive functions, primarily by enhancing neuroplasticity, increasing cerebral blood flow, and strengthening functional connectivity within key neural networks involved in cognitive control (Salas-Gomez et al., 2020). These physiological adaptations contribute to improvements across core domains of executive functioning, including inhibitory control, working memory, and cognitive flexibility. However, the specific mechanisms through which various types and intensities of exercise modulate executive functions remain insufficiently understood. To date, the literature has largely concentrated on aerobic activities, resistance training, and organized team sports, whereas rope skipping—a practical and time-efficient form of exercise—has received comparatively limited empirical attention, particularly in relation to its cognitive effects across different intensity levels (Salas-Gomez et al., 2020). Rope skipping has recently attracted scholarly interest due to its accessibility, low cost, and ease of integration into school-based physical education. In addition to its well-established cardiovascular benefits, rope skipping engages rhythm, timing, bilateral coordination, and sensorimotor integration—all of which are cognitively demanding and potentially beneficial for executive functioning (Singh et al., 2022). These characteristics suggest that rope skipping may serve as an effective modality for enhancing executive functions in adolescents. As such, systematic investigations into the cognitive effects of rope skipping at varying intensities may yield practical implications for school curricula and inform evidence-based strategies for promoting adolescent cognitive health. High-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) represent two widely adopted and empirically supported exercise modalities, each with distinct physiological and cognitive outcomes. HIIT is characterized by brief bursts of high-intensity activity interspersed with periods of low-intensity recovery, eliciting pronounced metabolic responses and neural activation in a compressed timeframe. This format has been associated with rapid improvements in executive functions, particularly in domains requiring inhibitory control and cognitive flexibility (Hadiono & Kushartanti, 2019). In contrast, MICT involves sustained, steady-state moderate-intensity exercise, which promotes longer-term and more stable enhancements in executive functioning, especially working memory (Gripp et al., 2021). Although the general cognitive benefits of physical activity are well established, direct comparisons of these two modalities within the context of school-based physical education remain limited, particularly among adolescent populations (Gripp et al., 2021).

Given the differential physiological mechanisms and cognitive targets of HIIT and MICT, it is imperative to investigate their relative efficacy in educational settings. To address this research gap, the present study introduces two structured intervention protocols—high-intensity interval jump rope training (HIIT-JR) and moderate-intensity continuous jump rope training (MICT-JR)—and examines their respective effects on executive functions in high school students. Through a randomized controlled design, this study aims to delineate the temporal trajectories and specific cognitive domains influenced by each training format. The findings are expected to offer theoretical grounding and practical guidance for optimizing physical education curricula to better support adolescents' cognitive development.Study Objectives:The specific objectives of this study are to:(1)Examine the overall effects of jump rope training on executive function in high school students;(2)Compare the differential impacts of HIIT-JR and MICT-JR on the three core domains of executive function:

inhibitory control, working memory, and cognitive flexibility;(3)Analyze the developmental trajectories of executive function subcomponents over the course of the intervention, with a view toward informing more targeted and evidence-based curricular designs.Hypotheses：Based on previous empirical findings, the following hypotheses are proposed:(1) Both HIIT-JR and MICT-JR will significantly enhance executive function in high school students compared to a control group; (2) HIIT-JR will yield more pronounced short-term improvements in inhibitory control and cognitive flexibility, while MICT-JR will produce greater long-term gains in working memory;（3）The magnitude and pattern of executive function improvements will be moderated by both exercise intensity and intervention duration. In summary, this study addresses a critical research gap by examining the effects of rope skipping—an accessible and time-efficient form of physical activity—on executive function in adolescents. Through the comparative analysis of high-intensity interval and moderate-intensity continuous rope skipping protocols, the study offers novel insights into how training intensity and structure influence distinct components of executive function.

These findings contribute to the evidence base for designing scientifically grounded and developmentally appropriate physical education interventions in secondary schools.From a pedagogical standpoint, the results underscore the potential of structured jump rope training to serve as an effective tool for enhancing students' cognitive functioning and learning readiness. Educators can leverage this evidence to develop targeted and adaptive physical education curricula that align with cognitive developmental needs, particularly during adolescence—a critical period for executive function maturation.Beyond classroom implementation, the study carries important implications for educational policy and school health frameworks. The findings support a shift from traditional, fitness-centered models of physical education toward more integrated and holistic approaches, wherein physical activity is strategically used to promote not only physical well-being but also cognitive and emotional development. Embedding such interventions within school systems can contribute to a more comprehensive educational paradigm, ultimately fostering academic success and long-term student well-being.

2. Materials and Methods

This study was conducted in strict accordance with the ethical principles set forth in the Declaration of Helsinki (2013 revision) (Ashcroft, 2008), and received formal approval from the Ethics Committee of the Sports Science Association at Beijing Sport University (Approval No. 202424H). Prior to participation, all procedures, objectives, and potential risks were fully explained to both the students and their legal guardians. Written informed consent was obtained from all participants and their guardians, affirming their voluntary participation in the study.

2.1 Participants

The required sample size was calculated using G*Power 3.1.9.2, assuming a medium effect size (f = 0.26), an alpha level of 0.05, and a statistical power of 0.80. Based on these parameters, the minimum required sample size was 26 participants (Cleophas & Zwinderman, 2016). To enhance statistical power and control for potential attrition, three public high schools in the suburban area of Xi'an, Shaanxi Province, China, were randomly selected and assigned to one of three groups: High-Intensity Interval Jump Rope training (HIIT-JR), Moderate-Intensity Continuous Jump Rope training (MICT-JR), or a control group. Each school contributed 40 students, ensuring a balanced distribution across gender, grade, baseline executive function, and physical activity levels. In total, 120 non-athlete students were recruited and included in the final sample (see Table 1).Prior to the intervention, all participants and their legal guardians were informed about the study's objectives, training procedures, and potential risks and benefits. Written informed consent was obtained from each participant, confirming voluntary participation.Inclusion criteria were as follows: (1) no participation in structured physical training programs within the past six months; (2) no medical or psychological conditions affecting executive function or physical performance; and (3) no history of severe musculoskeletal disorders or injuries.Exclusion criteria included: (1) inability to complete the intervention due to illness or injury; (2) training attendance rate below 80% during the intervention period; or (3) refusal to provide complete study data or voluntary withdrawal from the study.

Table 1: 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
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 intervention, all participants underwent a graded exercise test (GXT) to determine their individual maximum heart rate (HR_max) and resting heart rate (RHR). Based on established criteria for high- and moderate-intensity exercise zones—defined as 75–90% HR_max and 55–74% HR_max, respectively—the heart rate reserve (HRR) method was used to calculate individualized target heart rate (THR) ranges.To establish a standardized rhythm for jump rope cadence, all participants in the HIIT-JR and MICT-JR groups completed three 1-minute double-leg jump rope rhythm tests on non-consecutive days. Each participant's average cadence (beats per minute, bpm) was recorded. A shared rhythm distribution was analyzed, and the group mean was adopted as the prescribed target cadence to ensure consistency across participants within each group.To maintain exercise intensity within the designated thresholds throughout the intervention, the research team continuously monitored both jump rope cadence and real-time heart rate of representative participants whose cadence fell within the target range. This approach allowed for precise estimation and control of training load, ensuring that participants exercised consistently within their assigned intensity zone. The final prescribed cadences were as follows: (1)HIIT-JR group: 71 bpm (see Figure 1), MICT-JR group: 132 bpm (see Figure 2). During training sessions, participants wore Polar H10 heart rate monitors, enabling real-time physiological monitoring. Additionally, Ratings of Perceived Exertion (RPE) were collected in accordance with guidelines issued by the American College of Sports Medicine (ACSM) to provide subjective corroboration of exertion levels.

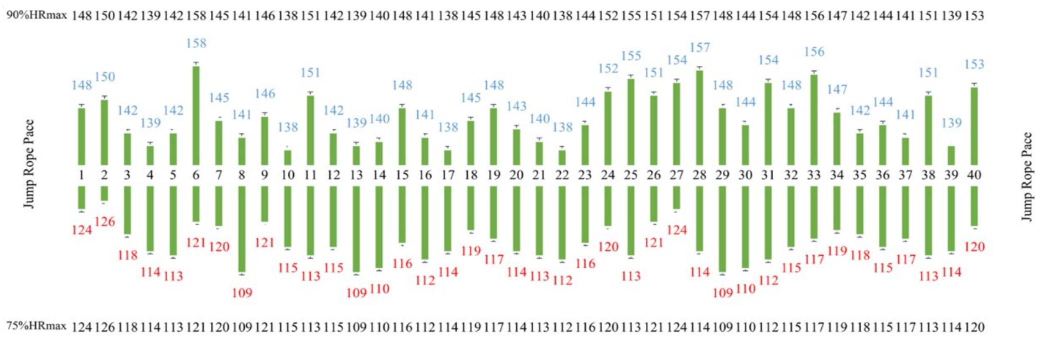

Figure 1: HII-JR One-Minute Jump Rope Pace Test.

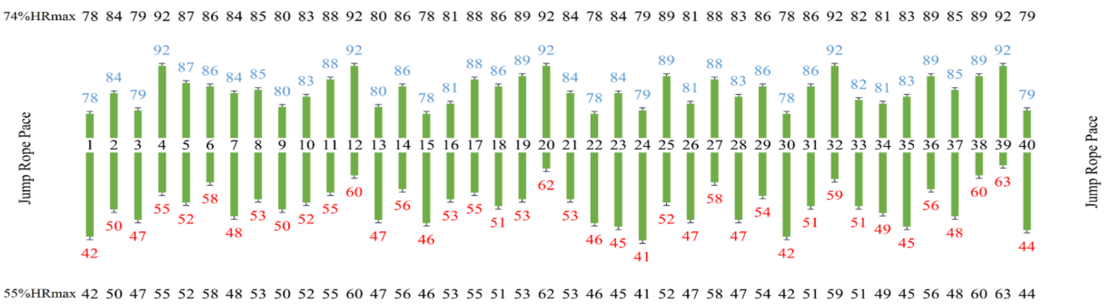

Figure 2: MIIC-JR One-Minute Jump Rope Pace Test.

2.3 Executive Function Test

2.3.1 Inhibitory Function Test

Inhibitory control was measured using a modified version of the Eriksen Flanker Task, a widely recognized paradigm for evaluating the capacity to suppress interference from irrelevant stimuli—one of the core components of executive function (Gyurak et al., 2009).The task comprised two blocks of 30 incongruent trials each. At the start of every trial, a fixation cross ("+") was presented at the center of the screen, followed by a stimulus array. Under incongruent conditions, the stimuli appeared as either ">>><>>" or "<<><<", wherein the central target arrow pointed in the opposite direction to the surrounding flanker arrows.Participants were instructed to focus solely on the direction of the central arrow while ignoring the flankers. The stimulus display remained on-screen for a maximum of 2000 milliseconds, during which participants were required to respond as quickly and accurately as possible using a keyboard. The response instructions were as follows: (1)Press the "F" key if the central arrow pointed left ("<"),(2) Press the "J" key if the central arrow pointed right (">"). Reaction time and response accuracy were recorded for each trial to assess inhibitory control performance.

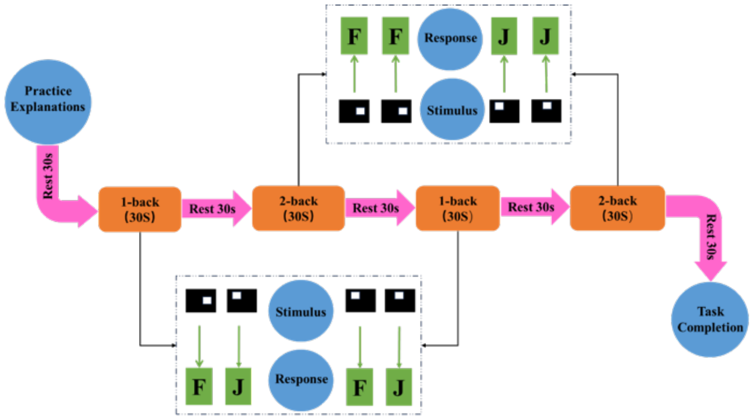

Figure 3: Flanker Task Procedure Diagram (Adapted from Chen: Chen (2023)).

2.3.2 Working Memory Test

Working memory was evaluated using the 2-back version of the N-back paradigm, a well-established task for assessing continuous updating and manipulation of information in working memory (Gyurak et al., 2009). The task comprised two blocks, each containing two 2-back sequences of 30 trials per sequence.In each trial, a white square was presented at random in one of several predefined screen locations. Each trial commenced with a fixation cross ("+"), followed by the stimulus display. Upon stimulus offset, the screen remained blank for 2000 milliseconds, during which participants were required to make a response. After the response window, the fixation cross reappeared, initiating the next trial. All trials were presented in a fixed, non-randomized sequence. In the 2-back condition, participants were instructed to monitor the location of the current stimulus and determine whether it matched the location of the stimulus presented two trials prior. The response protocol was as follows:(1) Press the "F" key if the current location matched that from two trials earlier, (2)Press the "J" key if the locations differed. Response accuracy and reaction time were recorded to assess working memory performance.A schematic representation of the trial sequence is provided in Figure 4.

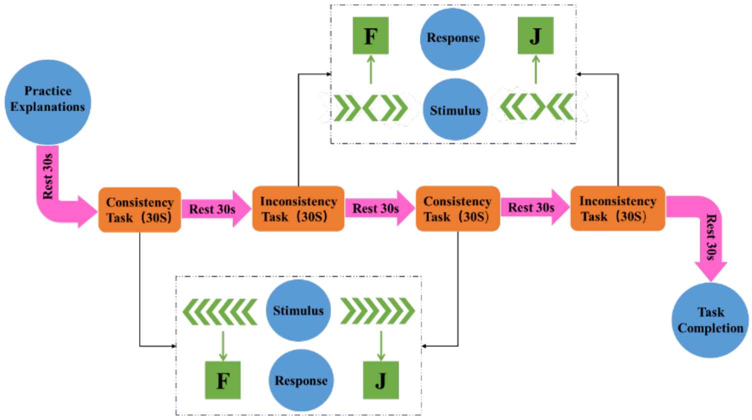

Figure 4: N-back Task Procedure Diagram (Adapted from Chen：Chen (2023)).

2.3.3 Cognitive Flexibility Test

Cognitive flexibility was assessed using the More-Odd Shifting paradigm. This task is designed to measure an individual's ability to switch between different cognitive rules, requiring participants to alternate between judgments of numerical magnitude and parity (Deák & Wiseheart, 2015).The task consists of three blocks, each comprising two alternating subtasks, with a total of 30 trials per block. In each trial, a single digit (ranging from 1 to 9, excluding 5) is randomly presented at the center of the screen. The digit appears in either red or green, which cues the participant to apply the corresponding rule. The trial structure is as follows: (1)A fixation cross "+" appears at the center of the screen;(2) Immediately following the fixation, a colored digit stimulus is displayed;(3) Participants are given a 2000 ms blank response window to make a judgment;(4) The color of the digit determines the task rule: Red digit → judge whether the number is greater than or less than 5; Green digit → judge whether the number is odd or even;(4) Participants respond by pressing the key corresponding to the current rule;(5) After each response, the fixation cross "+" reappears to prompt the next trial, forming a continuous loop. The task structure is illustrated in Figure 5.

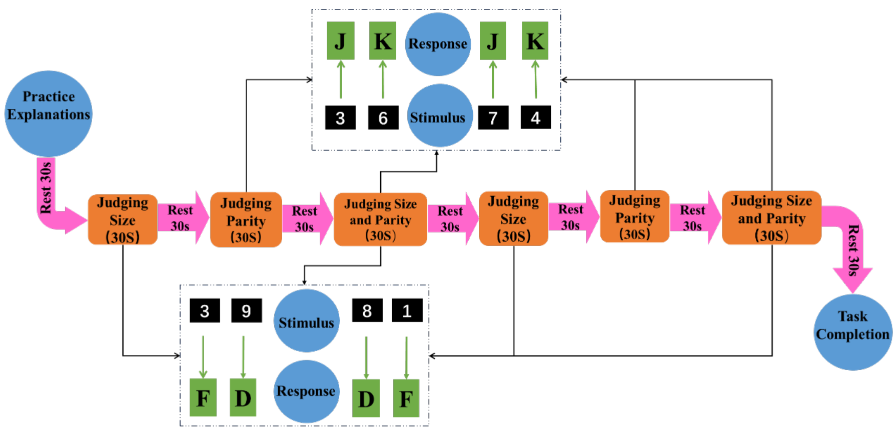

Figure 5: More-Odd Shifting Task Procedure Diagram (Adapted from：Chen (2023)).

2.4 Experimental Intervention Procedure

This study adopted a 3 (Group: HIIT-JR, MICT-JR, FT) × 3 (Time: Pre-test [T0], Mid-test [T1], Post-test [T2]) mixed factorial design to examine the time-dependent effects of jump rope training at different intensities on executive function in high school students. The primary dependent variables were reaction time (RT) outcomes derived from three core executive function tasks: inhibitory control, working memory, and cognitive flexibility.To ensure task comprehension and minimize practice effects, all participants completed 20 practice trials prior to each formal test session. Only those achieving an accuracy rate ⩾ 85% were permitted to proceed with the actual assessment phase.Executive function assessments were administered at three time points:(1) T0 (Week 1): Pre-intervention baseline;(2) T1 (Week 6): Midpoint of the intervention;(3) T2 (Week 12): Post-intervention endpoint. To monitor training compliance and perceived exertion, participants' Ratings of Perceived Exertion (RPE) were recorded before and after each training session. Mean RPE scores were used as indirect indicators of whether training intensity remained within the prescribed target zones.The intervention program spanned 12 consecutive weeks, with training conducted three times per week, and each session lasting approximately 17 minutes. A comprehensive schematic outlining the training protocol and assessment schedule is provided in Figure 1.

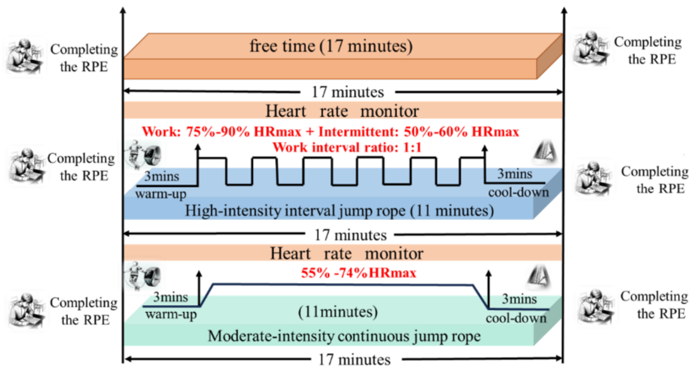

Figure 6: Experimental Program

2.5 Statistical Analysis

A repeated measures analysis of variance (RM ANOVA) was conducted to examine differences in response time (RT) and response accuracy across groups and time points. Mauchly's test of sphericity was used to assess whether the assumption of sphericity was met; when violations were detected, Greenhouse–Geisser corrections were applied to adjust the degrees of freedom accordingly (Ma et al., 2012).To assess the normality of data distributions, the Shapiro–Wilk test was employed. Upon confirming normality, post hoc pairwise comparisons were conducted using paired-sample t-tests, with Bonferroni correction applied to adjust for multiple comparisons and control the family-wise error rate (Potvin, 1996).A two-tailed alpha level of $p < 0.05$ was used to determine statistical significance in all analyses.

3. Results

3.1 Effects of Different Jump Rope Interventions on Inhibitory Function

The results of the repeated measures analysis are presented in Figure 7 and reveal the following trends:In the HIIT-JR group, reaction times significantly decreased across the intervention period. Specifically, pre-test reaction times were significantly longer than post-test values (P < 0.001), with a mean reduction of 17.012 ms. Although the difference between the pre-test and mid-test was not statistically significant (P = 0.128), a decreasing trend was observed (mean difference = 7.512 ms). Importantly, reaction times at mid-test were significantly longer than those at post-test (P < 0.001), with a mean difference of 9.500 ms, indicating a consistent downward trajectory over time.In the MICT-JR group, a similar pattern emerged. Reaction times at pre-test were significantly longer than at post-test (P < 0.001; mean difference = 14.522 ms), while the pre- to mid-test difference was not significant (P = 0.132; mean difference = 7.467 ms). However, a statistically significant reduction was observed from mid-test to post-test (P < 0.001), with a mean decrease of 7.055 ms, suggesting more gradual improvements compared to HIIT-JR. Between-group comparisons, illustrated in Figure 8, revealed further distinctions:(1) At the mid-test stage, the HIIT-JR group had shorter reaction times than the MICT-JR group, though the difference was not statistically significant (P = 0.258; mean difference = –6.552 ms). However, compared to the free activity control (FT) group, the HIIT-JR group showed significantly faster responses (P < 0.001; mean difference = –16.050 ms), and the MICT-JR group also exhibited a significant advantage (P = 0.040; mean difference = –9.497 ms).(2) At the post-test stage, the HIIT-JR group continued to demonstrate shorter reaction times than the MICT-JR group, with the difference approaching significance (P = 0.067; mean difference = –9.017 ms). Both intervention groups outperformed the FT group, with highly significant improvements observed in the HIIT-JR (P < 0.001; mean difference = –26.242 ms) and MICT-JR groups (P < 0.001; mean difference = –17.225 ms).

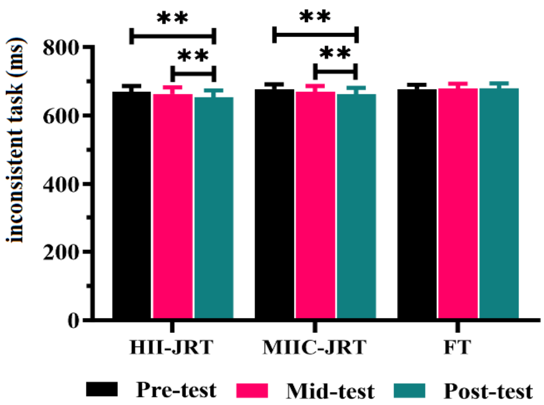

Figure 7: Within -Group Comparisons of Response Accuracy in the Inconsistent Task of Inhibitory Control Under Different Intensity Jump Rope Protocols.

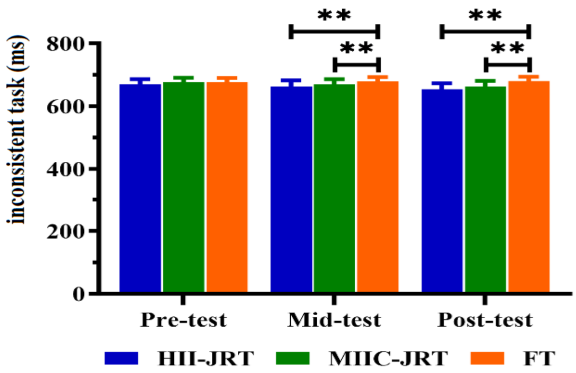

Figure 8: Between -Group Comparisons of Response Accuracy in the Inconsistent Task of Inhibitory Control Under Different Intensity Jump Rope Protocols.

3.2 Effects of Different Jump Rope Interventions on Working Memory

The results of the repeated measures analysis for working memory performance are presented in Figure 9:In the HIIT-JR group, reaction times significantly decreased across the intervention period. Specifically, pre-test reaction times were significantly longer than those at mid-test (P < 0.001; mean difference = 18.500 ± 2.043 ms), and a further significant reduction was observed between the pre-test and post-test stages (P < 0.001; mean difference = 27.142 ± 2.746 ms). Additionally, mid-test reaction times were significantly longer than those at post-test (P = 0.002; mean difference = 8.642 ± 2.512 ms), indicating a progressive improvement in working memory processing speed throughout the intervention.In the MICT-JR group, no significant difference was observed between pre-test and mid-test (P = 0.191; mean difference = 3.825 ± 2.043 ms). However, reaction times at post-test were significantly faster than at pre-test (P < 0.001; mean difference = 16.387 ± 2.746 ms) and mid-test (P < 0.001; mean difference = 12.563 ± 2.512 ms), suggesting that moderate-intensity training produced delayed but significant gains in working memory efficiency during the latter half of the intervention.Between-group comparisons, illustrated in Figure 10, yielded the following findings:(1) At mid-test, the HIIT-JR group exhibited faster reaction times than the MICT-JR group, though the difference was not statistically significant (P > 0.05; mean difference = –8.900 ± 9.684 ms). Compared to the free activity control group (FT), the HIIT-JR group demonstrated significantly shorter reaction times (P = 0.041; mean difference = –24.212 ± 9.684 ms), whereas the MICT-JR group did not significantly differ from the FT group (P = 0.350; mean difference = –15.312 ± 9.684 ms).(2) At post-test, the HIIT-JR group continued to outperform the MICT-JR group in reaction speed, although the difference remained non-significant (P > 0.05; mean difference = –4.980 ± 9.883 ms). Both intervention groups, however, showed significantly faster reaction times compared to the FT group, with the HIIT-JR group achieving a mean difference of –31.385 ± 9.883 ms (P = 0.006), and the MICT-JR group a mean difference of –26.405 ± 9.883 ms (P = 0.026).

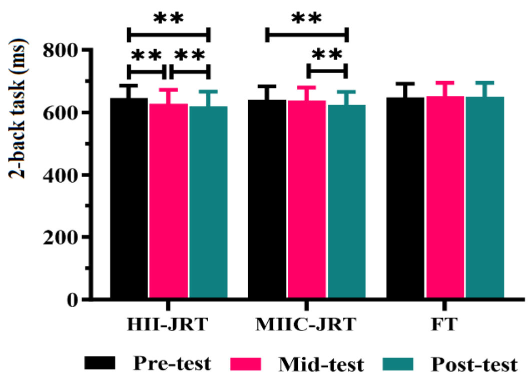

Figure 9: Within-Group Comparisons of Response Time in the 2-Back Task of Working Memory Under Different Intensity Jump Rope Protocols.

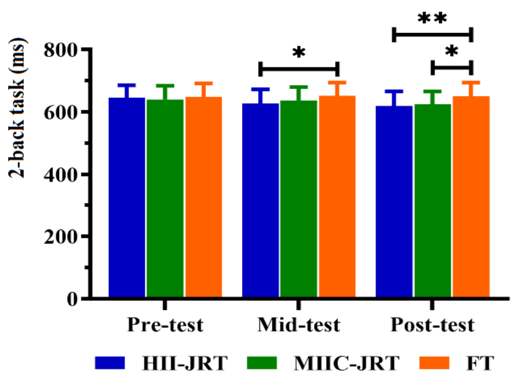

Figure 10: Between-Group Comparisons of Response Time in the 2-Back Task of Working Memory Under Different Intensity Jump Rope.

3.3 Effects of Different Jump Rope Interventions on Cognitive Flexibility

The results of the repeated measures ANOVA for cognitive flexibility are presented in Figure 11:In the HIIT-JR group, reaction times at the pre-test stage were longer than those at mid-test, although the difference did not reach statistical significance (P = 0.151; mean difference = 18.080 ± 9.147 ms). However, pre-test reaction times were significantly longer than post-test values (P = 0.024; mean difference = 25.425 ± 9.428 ms). Additionally, mid-test reaction times were significantly longer than those at post-test (P = 0.007; mean difference = 7.345 ± 2.361 ms), indicating a steady improvement in cognitive flexibility performance across the intervention period.In the MICT-JR group, although a reduction in reaction time was observed from pre-test to mid-test, the difference was not statistically significant (P > 0.05; mean difference = 7.555 ± 9.147 ms). Similarly, the comparison between pre-test and post-test stages did not reach significance (P = 0.465; mean difference = 13.500 ± 9.428 ms). However, mid-test reaction times were significantly longer than those at post-test (P = 0.039; mean difference = 5.945 ± 2.361 ms), suggesting that the beneficial effects of moderate-intensity jump rope training on cognitive flexibility emerged more clearly in the later phase of the intervention.Between-group comparisons, illustrated in Figure 12, revealed the following:(1) At mid-test, the HIIT-JR group displayed slightly longer reaction times than the MICT-JR group, though the difference was not statistically significant (P > 0.05; mean difference = –5.197 ± 9.210 ms). Compared to the free activity (FT) group, the HIIT-JR group demonstrated significantly faster reaction times (P = 0.046; mean difference = –22.650 ± 9.210 ms), while the MICT-JR group showed a non-significant reduction compared to the FT group (P = 0.182; mean difference = –17.453 ± 9.210 ms).(2) At post-test, the HIIT-JR group maintained faster reaction times than the MICT-JR group, though the difference did not reach statistical significance (P > 0.05; mean difference = –6.598 ± 9.931 ms). However, both experimental groups outperformed the FT group, with the HIIT-JR group showing a significant reduction in reaction time (P = 0.006; mean difference = –31.658 ± 9.931 ms) and the MICT-JR group also achieving a statistically significant improvement (P = 0.039; mean difference = –25.060 ± 9.931 ms).

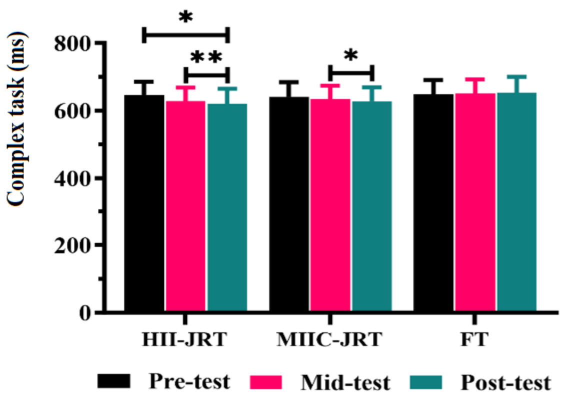

Figure 11 Within-Group Comparisons of Response Time in the Complex Task of Cognitive Flexibility Under Different Intensity Jump Rope Protocols.

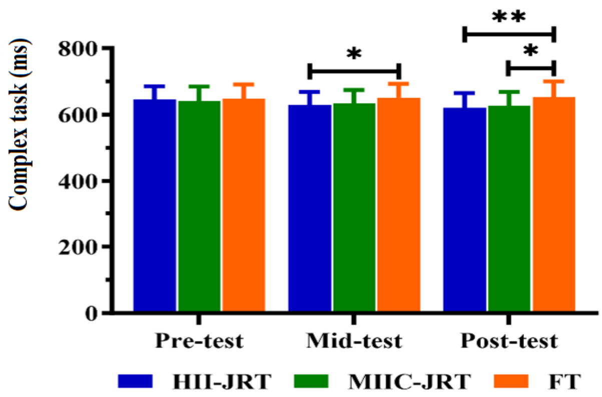

Figure 12 Between-Group Comparisons of Response Time in the Complex Task of Cognitive Flexibility Under Different Intensity Jump Rope Protocols.

4. Discussion

This study implemented a school-based pedagogical intervention to compare the differential effects of high-intensity interval jump rope training (HIIT-JR), moderate-intensity continuous jump rope training (MICT-JR), and free training (FT) on the three core components of executive function—inhibitory control, working memory, and cognitive flexibility—among high school students.In the inhibitory control task, both the HIIT-JR and MICT-JR groups demonstrated significant reductions in reaction time (RT) from pre-test to post-test, indicating enhanced ability to suppress irrelevant stimuli. Importantly, by the mid-intervention assessment, the HIIT-JR group exhibited slightly faster RTs than the MICT-JR group, suggesting that high-intensity training may lead to earlier gains in inhibitory control performance.For working memory, the HIIT-JR group achieved significant RT improvements at both mid- and post-test stages, with a magnitude of change exceeding that of the FT group. These findings point to a more robust and sustained benefit of high-intensity interval training on working memory efficiency compared to moderate or unstructured physical activity.Regarding cognitive flexibility, all groups showed modest RT improvements following the intervention. However, the difference between the HIIT-JR and FT groups was most pronounced at post-test, highlighting the superior effect of high-intensity jump rope training on flexible cognitive shifting and task-switching capacity.Taken together, these results underscore the potential of incorporating targeted, intensity-specific jump rope protocols into school-based physical education to foster not only physical fitness but also cognitive development in adolescents. Jump rope, as a complex, coordination-demanding physical activity, has been shown to enhance not only cardiorespiratory fitness and muscular strength but also cognitive function through multiple neurobiological pathways (Chen et al., 2020). A growing body of evidence confirms that aerobic exercise can significantly improve executive functions by modulating neurotransmitter activity, promoting the secretion of brain-derived neurotrophic factor (BDNF), and enhancing cerebral hemodynamics (Harada et al., 2004; Stillman et al., 2016). However, the majority of existing studies have examined the general cognitive benefits of aerobic exercise, while relatively few have explored the differential cognitive effects of distinct training modalities.In recent years, high-intensity interval training (HIIT) has emerged as a time-efficient and physiologically robust exercise strategy, attracting growing interest in both clinical and educational contexts. Compared to moderate-intensity continuous training (MICT), HIIT has been shown to induce comparable or superior adaptations in cardiorespiratory function and metabolic health within a shorter timeframe (Gormley et al., 2008). For instance, meta-analytic evidence indicates that HIIT outperforms MICT in improving insulin sensitivity and cardiovascular outcomes (Jelleyman et al., 2015; Ramos et al., 2015). Nevertheless, the cognitive effects of HIIT, particularly in adolescent populations, remain underexplored.A notable study by Mekari et al. demonstrated that HIIT led to greater improvements in inhibitory control and cognitive flexibility than MICT in young adults (Mekari et al., 2020). Furthermore, even a single session of HIIT was found to significantly enhance working memory performance, suggesting that HIIT may confer acute and potent cognitive benefits. One plausible mechanism is the elevated cardiovascular load associated with HIIT, which promotes increased cerebral blood flow and subsequent delivery of oxygen and nutrients to brain regions critical for executive control (Calverley et al., 2020). Additionally, HIIT has been shown to elicit a substantial rise in peripheral BDNF levels, which plays a key role in neurogenesis, synaptic plasticity, and overall cognitive enhancement (Jiménez-Maldonado et al., 2018). However, existing research has primarily focused on adult populations and has largely employed single-session acute exercise paradigms. Adolescents, by contrast, are in a critical period of rapid physical and cognitive development, characterized by heightened neuroplasticity. This may render them more responsive to exercise-based interventions, with potentially distinct cognitive outcomes compared to adults (Sawyer et al., 2018). Moreover, the cognitive benefits of long-term, systematic exercise training may differ substantially from the transient effects of a single bout of physical activity. Therefore, there is a pressing need for longitudinal studies targeting adolescent populations to elucidate the underlying mechanisms by which different exercise modalities influence cognitive development.Compared with traditional aerobic exercises such as walking or jogging, rope skipping (jump rope) imposes a higher cardiovascular demand while also requiring enhanced coordination and neuromuscular control (Trecroci et al., 2015). During rope skipping, individuals must perform rapid and precise limb movements within a short time frame, significantly increasing reliance on neuromotor regulation (Duzgun et al., 2010). In addition, the continuous need to adapt movements to rhythmic changes promotes attentional allocation and cognitive flexibility (Yoshida et al., 2003). Therefore, jump rope training may offer superior cognitive benefits compared to conventional aerobic modalities.Based on the above theoretical rationale and empirical findings, this study designed a 12-week jump rope intervention to systematically investigate its impact on executive function. Compared with previous research, this study introduces several methodological innovations:

(1) High ecological validity: The study recruited in-school high school students as participants, enhancing the applicability of the findings to real-world educational settings.(2) Extended intervention duration: A 12-week training protocol was employed to allow the examination of cumulative cognitive benefits of exercise over time.(3) Direct comparison of training modalities: By integrating high-intensity interval jump rope training (HIIT-JR) and moderate-intensity continuous jump rope training (MICT-JR), the study provides comparative evidence on how training intensity modulates cognitive outcomes.(4) Comprehensive executive function assessment: The study evaluates all three core components of executive function—response inhibition, working memory, and cognitive flexibility—offering a multidimensional understanding of the cognitive benefits of jump rope training. The results of this study demonstrated that both high-intensity interval jump rope training (HIIT-JR) and moderate-intensity continuous jump rope training (MICT-JR) significantly improved executive function following a 12-week intervention, with these

cognitive benefits maintained over the short term post-intervention. This finding further substantiates the positive effects of exercise interventions on cognitive performance and expands the empirical foundation for the application of jump rope training in adolescent cognitive development.Comparative analysis revealed that the HIIT-JR group exhibited a greater enhancement in executive function than the MICT-JR group, particularly from baseline to mid-intervention and baseline to post-intervention. These results suggest that high-intensity interval training may exert superior effects on executive functioning compared to moderate-intensity continuous training, especially in the domains of inhibitory control and cognitive flexibility.The cognitive advantage of HIIT-JR may be attributed to its ability to simultaneously activate multiple physiological and neurocognitive mechanisms:(1) Greater cardiovascular load: Compared to MICT, HIIT imposes a higher demand on the cardiovascular system. Its alternating bouts of high-intensity effort and recovery elicit pronounced heart rate fluctuations, which may enhance cardiovascular and cerebral blood flow regulation—thereby ensuring improved perfusion to support cognitive processes (Courteix et al., 1998; Gad & Jayaraj, 2020).(2) Frequent intensity transitions enhance cognitive flexibility: The rapid shifts in intensity during HIIT require individuals to continuously adapt to varying physical demands. This dynamic adjustment process may reinforce neural circuits associated with task-switching and attentional shifting, thus improving cognitive flexibility (Byers et al., 2018). (3) Heightened physiological stress promotes neuroplasticity: HIIT has been shown to induce a high level of physiological stress, which in turn stimulates the upregulation of neurotrophic factors such as brain-derived neurotrophic factor (BDNF). This upregulation supports synaptic plasticity and neural connectivity, thereby facilitating improvements in executive function (Jache et al., 2016). However, the HIIT-JR group did not exhibit a significant advantage in working memory performance. This finding suggests that distinct components of executive function may differ in their sensitivity to exercise intensity and modality (Spence et al., 2011). Specifically, working memory is primarily supported by the frontoparietal network, whereas inhibitory control and cognitive flexibility are more closely associated with the prefrontal–striatal circuitry (Jache et al., 2016).

Accordingly, the neuroadaptive effects elicited by high-intensity interval training may exert region-specific influences on the brain, a hypothesis that warrants further investigation using neuroimaging techniques such as fMRI or fNIRS.Although the HIIT-JR group exhibited some cognitive advantages in the post-intervention phase, the differences relative to the MICT-JR group did not reach statistical significance. This observation may indicate that, over extended training durations, the cognitive benefits of HIIT and MICT may converge. Previous studies have suggested that the cognitive enhancement effects of exercise are partly mediated by improvements in cardiorespiratory fitness and cerebral perfusion regulation (Bhardwaj et al., 2007). Once the exercise stimulus surpasses a physiological threshold, different modalities may lead to comparable neurophysiological adaptations, ultimately resulting in similar executive function outcomes.In sum, this study employed a randomized controlled trial to explore the differential impacts of high-intensity and moderate-intensity jump rope training on executive function in adolescents. The results provide novel empirical support for the relationship between exercise intensity and cognitive development. Compared to MICT, HIIT may offer greater cognitive benefits, potentially due to its greater physiological load and higher neuromotor complexity (Grob et al., 2005).These findings carry meaningful educational implications. Integrating diverse exercise intensities and cognitively engaging movement patterns into physical education and extracurricular programming may serve as an effective strategy to promote synergistic physical and cognitive development in adolescents (MacMurren, 1985). To further refine exercise-based cognitive interventions, future research should employ longitudinal designs and incorporate neurobiological markers to elucidate the underlying mechanisms driving cognitive improvements in youth populations. Despite its valuable contributions, this study has several limitations that warrant careful consideration:(1) Limited sample size and generalizability:The relatively small sample size and the exclusive focus on high school students limit the generalizability of the findings. Consequently, the conclusions may not be applicable to broader adolescent populations or individuals from varying demographic and socioeconomic backgrounds. Future studies should aim to recruit larger, more diverse samples to enhance statistical power and external validity.(2) Absence of long-term follow-up assessments:Due to logistical constraints, this study did not include follow-up evaluations beyond the 12-week intervention period. As a result, the durability of the observed improvements in executive function remains unknown. Longitudinal designs incorporating delayed post-tests are needed to determine whether the cognitive benefits of jump rope training can be sustained over time.(3) Lack of mechanistic investigation:This study relied solely on behavioral outcome measures and did not incorporate any neurophysiological or neuroimaging assessments. Thus, it is not possible to directly identify the neural mechanisms underlying the observed cognitive enhancements (Dooley et al., 2017). To address this gap, future research should integrate multimodal assessment techniques, including functional neuroimaging (e.g., fMRI, fNIRS) and electrophysiological methods (e.g., EEG), to elucidate the neurobiological pathways through which physical activity exerts its effects on executive function (Troncoso et al., 2009).Recommendations for future research include:(i) Recruiting larger and more heterogeneous participant cohorts to enhance the generalizability of findings;(ii) Implementing extended longitudinal follow-up protocols to assess the long-term sustainability of training effects;(iii) Incorporating objective neural indices to clarify the cognitive and biological mechanisms underlying exercise-induced benefits.By addressing these limitations, future studies can contribute to a more comprehensive understanding of how targeted physical activity interventions influence adolescent cognitive development. This randomized controlled trial systematically investigated the effects of jump rope training on executive function in adolescents. The results demonstrated that a 12-week structured intervention significantly enhanced key domains of executive function—including response inhibition, working memory, and cognitive flexibility—with improvements sustained into the short-term post-intervention phase. Notably, high-intensity interval jump rope training (HIIT-JR) produced superior gains in inhibitory control and cognitive flexibility compared to moderate-intensity continuous jump rope training (MICT-JR), while both modalities elicited comparable improvements in working memory.These findings add to the growing body of evidence highlighting the cognitive benefits of physical activity in youth populations and underscore the potential of jump rope training as an efficient, scalable, and accessible intervention for cognitive enhancement. From an applied perspective, the results support the integration of structured, intensity-tailored jump rope exercises into school-based physical education programs and individualized training regimens aimed at fostering cognitive development during adolescence.Future research should aim to (i) recruit larger and more diverse samples to improve generalizability, (ii) employ advanced assessment techniques—such as neuroimaging and physiological monitoring—to elucidate the underlying mechanisms, and (iii) conduct long-term follow-up evaluations to determine the durability of intervention effects. Such efforts will help inform the design of more targeted and evidence-based strategies to optimize both physical and cognitive health outcomes in youth.

5. Conclusions

This study employed a randomized controlled trial design to systematically investigate the effects of a 12-week high-intensity interval jump rope training (HIIT-JR) and moderate-intensity continuous jump rope training (MICT-JR) on executive function in high school students. The findings revealed that both training modalities significantly improved adolescents' inhibitory control, working memory, and cognitive flexibility, with these cognitive gains sustained in the short-term following the intervention. Comparative analyses further showed that HIIT-JR conferred relatively greater benefits for inhibitory control and cognitive flexibility, whereas no significant difference emerged between the two training modalities regarding working memory enhancement. Overall, the study contributes to the growing body of empirical evidence supporting the cognitive benefits of physical activity interventions in adolescents. The results suggest that regular jump rope training is an effective approach to promoting executive function, with HIIT-JR offering superior cognitive advantages likely due to its higher physiological demands and greater cognitive engagement. These findings hold practical significance for the development of secondary school physical education curricula and extracurricular programs, underscoring the importance of incorporating training modalities that vary in intensity and movement complexity to optimize both physical and cognitive development in youth.Nonetheless, several limitations warrant consideration. These include a relatively small sample size, the absence of long-term follow-up assessments, and a lack of direct examination of the neurobiological mechanisms underlying the cognitive benefits of exercise (Jain et al., 2015). Future research should aim to address these limitations by increasing sample sizes, incorporating longitudinal designs, and employing multimodal assessment techniques such as neuroimaging and biomarker analysis. Elucidating the optimal parameters of exercise interventions will provide a more rigorous and sustainable foundation for enhancing cognitive function and physical health among adolescents (Jain et al., 2015).

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.

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