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Jiecai Zheng
Shandong University
Yuxi Shi
Shandong Sport University
Liu Mu
Shandong Sport University
Chenchen Wang
Shandong Sport University
Jiayu Chen
Shenzhen University
Wei Liang
Shenzhen University
Lin Zhou
zhoulin@sdpei.edu.cn

Shandong Sport University

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Effects of Exercise Snacks on Motor Coordination in Children with Obesity: A Pilot Randomized Controlled Trial

Jiecai Zheng[1], Yuxi Shi[2], Liu Mu[2], Chenchen Wang[2], Jiayu Chen[3], Wei Liang[3*], Lin Zhou[4*]

1 School of Physical Education, Shandong University, Jinan, China, 250100

2 School of Graduate Education, Shandong Sport University, Jinan, China, 250102

3 School of Physical Education, Shenzhen University, Shenzhen, China, 518060

4 School of Sport and Health, Shandong Sport University, Jinan, China, 250102

* Corresponding author, zhoulin@sdpei.edu.cn

Abstract:

Background Obesity in children and adolescents has become a major global public health problem and is often accompanied by delayed development of motor coordination. Exercise snacks refers to completing multiple short, structured exercise sessions distributed throughout the day, and is more time-efficient and flexible than traditional exercise interventions. However, evidence regarding its effects on motor coordination in children with obesity remains limited. This study aimed to evaluate the effects of a 10-week school- and home-based fragmented high-intensity cordless jump rope exercise intervention on motor coordination in children with obesity.

Methods A single-blind, two-arm randomized controlled trial design was used. Forty-eight children with obesity aged 6–12 years were recruited from a primary school in Shenzhen. They were randomly assigned at a 1:1 ratio to an intervention group ($N = 24$) and a control group ($N = 24$). The intervention group performed exercise snacks on 3 nonconsecutive days per week for 10 weeks. On each intervention day, participants completed three 3-minute exercise sequences (1 minute of warm-up at 50%–70% HRmax; 1 minute of high-intensity cordless jump rope at 80% – 90% HRmax; and 1 minute of cool-down at ≤50% HRmax), with two sessions conducted at school and one at home per week. The control group maintained their usual lifestyle and did not receive any additional exercise intervention. Motor coordination was assessed using the Movement Assessment Battery for Children–Second Edition (MABC-2). Feasibility outcomes included study completion rate, exercise bout completion rate, exercise intensity adherence rate, and adverse events. Repeated-measures analysis of variance was used to test intervention effects according to the intention-to-treat principle, with partial eta squared (η^2p) as the effect size.

Results Baseline characteristics were balanced and comparable between the two groups ($P_{all} > 0.05$). The study completion rate was 91.7% (22/24) in the intervention group and 83.3% (20/24) in the control group ($P = 0.666$). In the intervention group, the completion rate of the 90 prescribed high-intensity exercise bouts was 94.17% ± 5.80%. Of the valid monitoring records, 85.42% (205/240) reached the prescribed intensity range. The mean monitored intensity was 81.71% ± 1.73% HRmax. No adverse events were reported during the intervention. Significant group × time interaction effects were found for the total motor coordination score ($F_{(1, 46)} = 21.87$, $P < 0.001$, $\eta^2p = 0.32$), aiming and catching ($F_{(1, 46)} = 20.49$, $P < 0.001$, $\eta^2p = 0.31$), and balance ($F_{(1, 46)} = 5.53$, $P = 0.023$, $\eta^2p = 0.11$), with greater improvements in the intervention group than in the control group (total score:

+2.04 vs +0.08; aiming and catching: +1.33 vs +0.17; balance: +0.50 vs +0.04). No significant group × time interaction effect was observed for manual dexterity ($F_{(1, 46)} = 2.50$, $P = 0.121$, $\eta^2p = 0.05$). Results of the per-protocol sensitivity analysis were consistent with those of the intention-to-treat analysis.

Conclusions The 10-week school- and home-based fragmented high-intensity cordless jump rope exercise intervention was feasible and improved overall motor coordination in children with obesity, with stable effects on aiming and catching and balance, but no significant improvement in manual dexterity. These findings suggest that the effects of exercise snacks on motor coordination are dimension-specific and may depend on the neuromuscular compatibility between the intervention content and the targeted motor dimensions. Future interventions should incorporate fine motor tasks into gross motor training to promote comprehensive development of motor coordination in children with obesity.

Trial registration Chinese Clinical Trial Registry, ChiCTR2200066143. Registered on 25 November 2022.

Keywords exercise snacks; childhood obesity; motor coordination; cordless jump rope; school–home intervention

Background

Obesity in children and adolescents has become a major public health problem requiring urgent action in China and worldwide [1, 2]. National survey data indicate that the combined prevalence of overweight and obesity among Chinese children and adolescents aged 7–18 years was 23.4% in 2019; it is projected that, in the absence of effective intervention, the prevalence of overweight and obesity among school-aged children in China will reach 32.7% by 2030 [3]. Childhood obesity is not only closely associated with cardio-metabolic abnormalities such as insulin resistance, hypertension, and dyslipidemia, but may also increase the risk of cardiovascular disease in adulthood [4]. In recent years, the impact of obesity on the development of motor function in children has received increasing attention, and obesity may particularly impair their motor coordination.

Motor coordination (MC) is an essential component of motor development in children and reflects the ability to perform coordinated and precise motor tasks through the integration of sensory information, central neural regulation, and musculoskeletal synergy [5, 6]. Numerous studies have shown that, compared with normal-weight children, children with overweight and obesity generally exhibit delayed development of motor coordination, primarily manifested as deficiencies in fundamental motor skills, balance, and motor control [7–9]. Poor motor coordination not only affects the quality of motor task performance but is also associated with insufficient participation in physical activity and lower exercise self-efficacy, potentially forming a vicious cycle of "obesity–motor coordination impairment–reduced activity" [10, 11]. Therefore, improving MC may be an important intervention target for promoting physical activity participation and healthy development in children with obesity.

Exercise intervention is considered one of the important strategies for improving physical

function and promoting healthy development in children with obesity [12]. Previous studies have shown that structured exercise training can improve cardiorespiratory fitness, body composition, and metabolic health in children, and can promote motor skill learning and development [10, 13, 14]. However, traditional exercise interventions generally require fixed schedules and specific implementation settings, which may increase practical challenges for children's long-term participation. In addition, reduced motor competence and insufficient physical activity in children with obesity may further decrease their acceptance of and sustained participation in exercise interventions [15, 16]. Therefore, it is of considerable importance to explore novel exercise modalities that are more flexible, have lower barriers, and can be readily integrated into children's daily lives.

In recent years, exercise snacks has attracted attention as an emerging exercise modality. This modality refers to distributing multiple short-duration, purposeful, structured exercise sessions throughout the day. Among these, sprint-type exercise snacks typically involves high-intensity activities lasting no more than 1 min per session, aiming to increase physical activity exposure, interrupt prolonged sedentary behavior, and promote health [17, 18]. Due to its low time commitment and high implementation flexibility, exercise snacks can be readily integrated into children's daily learning and living contexts, offering a novel intervention strategy for enhancing children's exercise participation. The development of MC depends on repetitive motor practice and the accumulation of motor experience [19, 20], and exercise snacks may provide children with more opportunities for motor practice by increasing the frequency of daily exercise stimuli. Cordless jump rope promotes upper- and lower-limb coordination through the rhythmic coordination of continuous jumping and upper-limb rope-swinging movements, which aligns with the requirements of motor coordination training [21]; compared with traditional jump rope, it retains the basic jumping pattern while reducing rope interference, potentially reducing experiences of task failure and improving training acceptability in children with obesity. In addition, cordless jump rope has low facility requirements and can be flexibly implemented in school and home environments, consistent with the short-duration, high-frequency, and easy-to-implement characteristics of exercise snacks [22]. Therefore, high-intensity cordless jump rope may be a feasible modality for exercise snacks interventions in children with obesity.

Although exercise snacks has received widespread attention in recent years, evidence from studies targeting children with obesity and using motor coordination as the primary outcome remains limited. Existing studies on exercise snacks have mainly focused on healthy adults or older adults, with most examining physical fitness, metabolic health, or sedentary behavior interventions, whereas randomized controlled trials addressing improvements in motor function in children with obesity, particularly those based on school–home dual settings, remain scarce [23–25]. Therefore, the present study employed a randomized controlled trial design to systematically evaluate the effects of a 10-week fragmented cordless jump rope exercise intervention on MC in children with obesity, aiming to provide empirical evidence for optimizing exercise intervention strategies and promoting health in childhood obesity.

Methods

Study Design

This study employed a single-blind, two-arm randomized controlled trial design to examine the effects of a 10-week exercise snacks intervention on motor coordination in children with obesity. Two groups were established. The intervention group received a 10-week exercise snacks intervention (using high-intensity cordless jump rope, 3 days per week, with 3 short sessions per day, 2 at school and 1 at home), and the intervention was implemented in a dual school–home setting. The control group did not receive any exercise intervention during the intervention period and only maintained regular school physical education classes and recess activities (Figure 1). To adhere to the principle of equal benefit in research ethics, participants in the control group will receive, free of charge, an introduction to the exercise snacks intervention and related materials after the study ends. The design, implementation, and reporting of this study protocol strictly adhered to the SPIRIT guidelines [26] and the CONSORT statement [27]. The trial protocol was registered with the Chinese Clinical Trial Registry (registration number： 25YJCZH401) and was reviewed and approved by the Medical Research Ethics Committee of Shenzhen University (No. PN-202400005).

Participants

This study recruited school-aged children with obesity aged 6–12 years from a primary school in Shenzhen. All participants and their guardians voluntarily participated after fully understanding the study content and provided written informed consent. Inclusion criteria: (1) age 6–12 years; (2) BMI above the cutoff corresponding to the 95th percentile of the sex- and age-specific BMI reference standards for Chinese children and adolescents [28]; (3) no exercise risk according to PAR-Q screening; (4) no severe cognitive or psychiatric disorders; and (5) no participation in any systematic exercise training program within the previous 6 months. Exclusion criteria: (1) non-obese children; (2) organic diseases such as congenital heart disease, epilepsy, or asthma that make moderate-to-high-intensity exercise unsuitable; and (3) presence of limb motor impairment or mobility limitations.

A priori sample size estimation was performed using G*Power 3.1 software. Based on Krombholz [29] regarding the effect of physical activity intervention on motor skill improvement in overweight children (partial eta squared = 0.18), with α set at 0.05, power ($1-\beta$) set at 0.8, and accounting for a 20% loss to follow-up, at least 48 participants (i.e., 24 per group) were required to achieve robust statistical inference.

Randomization, allocation concealment, and blinding

A researcher not involved in intervention implementation or data collection generated a random number list using Excel and randomly assigned eligible participants to the intervention group or the control group at a 1:1 ratio. The allocation results were sealed in opaque envelopes, which were opened after baseline testing to execute group assignment, thereby achieving allocation concealment. Given the recognizability of the intervention format, both the exercise intervention implementers and the participants were aware of group allocation; however, the data collectors did not have access to participants' group allocation information, thereby ensuring objectivity in outcome assessment. Therefore, this study adopted an assessor-blinded design.

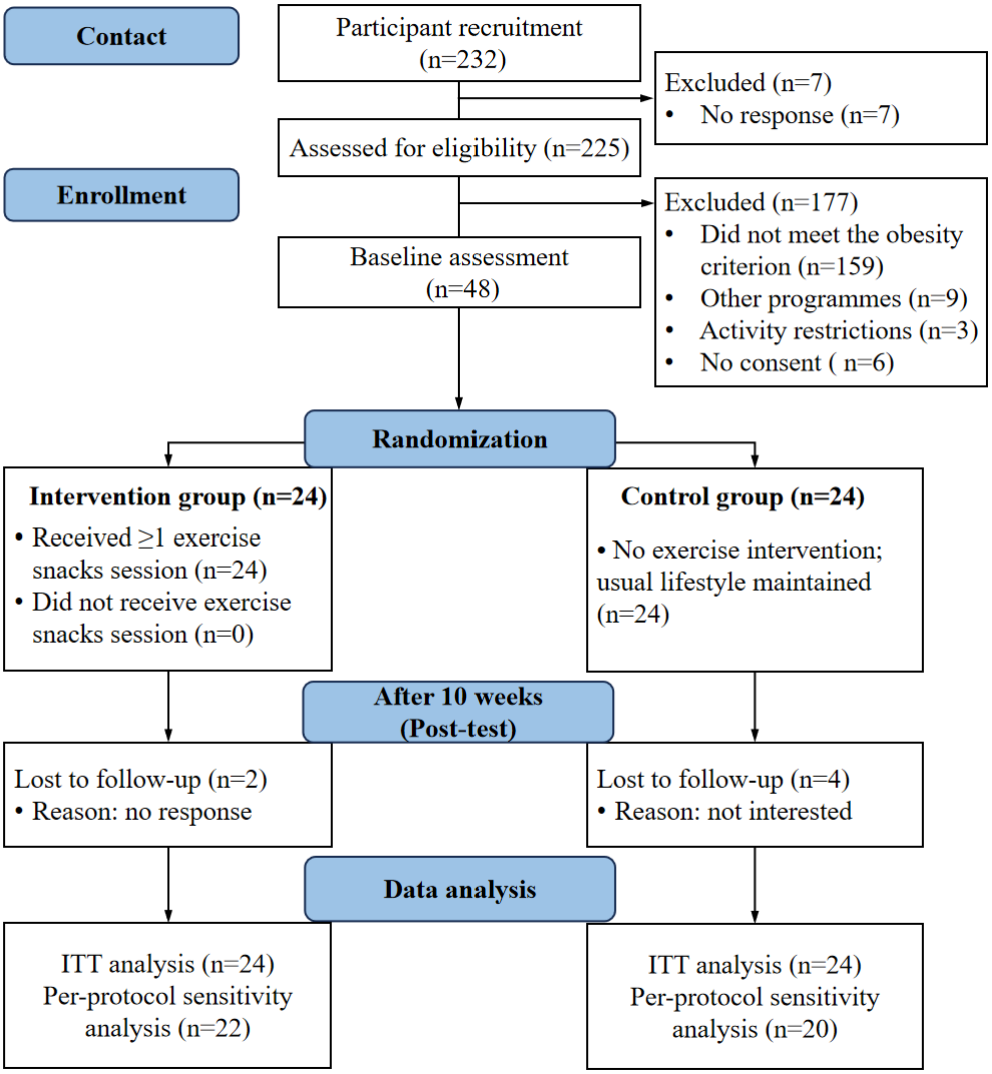


Figure 1. CONSORT flow diagram

Intervention program

High-intensity cordless jump rope was the specific exercise modality for exercise snacks in this study. During the high-intensity exercise phase, participants primarily performed two basic movements, namely double-foot jumps and jumping jacks, synchronized with a standardized musical beat at a cadence of approximately 170 beats per minute. One week before the formal intervention began, participants received standardized instruction in movement technique and completed familiarization practice at the prescribed cadence. This preparatory period was established to enhance consistency in movement execution and ensure exercise safety.

The formal intervention lasted 10 weeks. Previous studies on exercise snacks and other short-duration exercise interventions have mostly used intervention periods of 8–12 weeks [30]. Therefore, a 10-week period was selected in this study, which can both ensure sufficient repeated exposure and facilitate smooth implementation within the school semester [31]. Participants in the intervention

group performed cordless jump rope exercise snacks on 3 nonconsecutive days per week to allow adequate recovery time between intervention days. On each intervention day, participants completed three 3-minute exercise sequences, with 1–4 hours between sequences. Each sequence consisted of 1 minute of warm-up at 50%–70% of estimated maximum heart rate (HRmax); 1 minute of high-intensity cordless jump rope exercise snacks at 80%–90% HRmax; and 1 minute of cool-down including stretching and recovery movements at no more than 50% HRmax. HRmax was estimated using the formula 208 − (0.7 × age), which has been validated in children and adolescents [32]. The three daily exercise sequences were scheduled during the morning recess, afternoon recess, and after school, respectively. Over the entire intervention period, a total of 90 prescribed high-intensity exercise snacks sessions were completed, equivalent to 90 minutes of high-intensity exercise.

The morning and afternoon exercise sequences were completed at school, while the after-school sequence was completed at home under parental supervision. Previous studies have shown that parental involvement and school–home collaboration facilitate the implementation of child health promotion programs and help children develop health-related behaviors [33]. Therefore, on each intervention day, the intervention combined two supervised school-based exercise sequences with one parent-supervised home-based exercise sequence, integrating exercise into daily life at school and at home.

The school-based exercise sequences were organized and supervised by trained members of the research team, who recorded the completion of the prescribed exercise repetitions and monitored movement execution. The completion of home-based exercise sequences was documented through video check-ins on the “Daily Rope Skipping” application or paper logs completed by parents. The research team reviewed the home exercise records every two weeks and provided feedback to the participating children and their parents.

Standardized audio beats were used throughout the intervention period to regulate movement rhythm. To assess whether participants completed exercise at the prescribed intensity, one intervention time point was randomly selected each week, at which all participants in the intervention group wore Polar H10 heart rate monitors. Heart rate was monitored continuously throughout the selected 3-minute exercise sequence, and heart rate data recorded during the 1-minute high-intensity exercise snacks phase were used to determine whether the target intensity of 80%–90% HRmax was achieved. If the monitored heart rate fell outside the target range, participants were instructed to adjust movement rhythm or amplitude in subsequent exercise phases. Regular feedback and verbal encouragement were also provided to promote active engagement and completion of the prescribed exercise repetitions.

Participants in the control group maintained their usual lifestyle during the 10-week study period and did not receive any additional exercise intervention. After the post-intervention assessment was completed, the complete intervention materials were provided to the control group. The intervention content is shown in Figure 2.

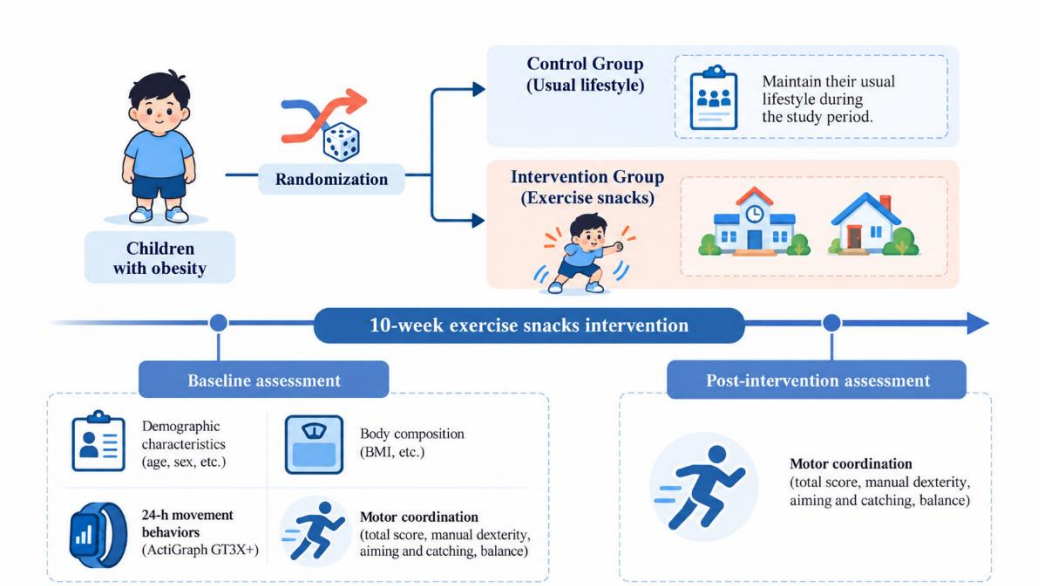


Figure 2. Study design and assessment schedule for the exercise snacks intervention. Children with obesity were randomly allocated to the intervention group or control group. The intervention group received a 10-week exercise snacks intervention, whereas the control group maintained their usual lifestyle. Baseline assessments included demographic characteristics, body composition, 24-h movement behaviors measured using the ActiGraph GT3X+, and motor coordination. Motor coordination was reassessed immediately after the intervention and included total score, manual dexterity, aiming and catching, and balance.

Outcome measures

Motor coordination

Motor coordination was assessed using the Movement Assessment Battery for Children–Second Edition (MABC-2) [34]. This instrument has been validated in Chinese children and has demonstrated good reliability and validity (internal consistency reliability, 0.81–0.87) [35]. In this study, according to the age distribution of participants, Age Band 2 (7–10 years) and Age Band 3 (11–16 years) were used to assess three dimensions: Manual Dexterity, Aiming & Catching, and Balance. The test items for each age band were as follows. In Age Band 2, Manual Dexterity included Placing Pegs, Threading Lace, and Drawing Trail 2; Aiming & Catching included Catching with Two Hands and Throwing Beanbag onto Mat; and Balance included One-Board Balance, Walking Heel-to-Toe Forwards, and Hopping on Mats. In Age Band 3, Manual Dexterity included Turning Pegs, Triangle with Nuts and Bolts, and Drawing Trail 3; Aiming & Catching included Catching with One Hand and Throwing at Wall Target; and Balance included Two-Board Balance, Walking Toe-to-Heel Backwards, and Zig-Zag Hopping. Each test item allowed three attempts: the first was a practice trial, and the latter two were formal tests, with the best score recorded as the final result. During testing, assessors did not provide any form of guidance or prompting to participants. After testing, researchers converted raw scores for each item into standard scores using the MABC-2 online scoring system; higher standard scores indicated better motor coordination. To ensure the reliability and consistency of measurement results, within two weeks after the initial test,

two trained assessors randomly selected 15% of the sample for retesting. Cronbach's alpha coefficients for each dimension ranged from 0.78 to 0.83, indicating good test-retest reliability of MABC-2 measurements in this study.

Potential covariates

In this study, demographic characteristics, anthropometric indicators, and baseline 24-hour movement behavior were assessed as potential covariates [19]. Primary caregivers reported the child's sex and age, caregiver age, and perceived family economic status (classified as low, medium, or high). Trained researchers measured height and weight according to standardized procedures, with children wearing light clothing and no shoes. BMI was calculated as weight (kg) divided by height (m) squared [36].

Information on 24-hour movement behavior was collected using an ActiGraph GT3X^{+} triaxial accelerometer (ActiGraph LLC, Pensacola, FL, USA). Except for water-based activities such as swimming and bathing, all participants were encouraged to wear the device continuously for 7 days (including 2 weekend days), positioned at the right waist/sacrum. Criteria for valid data were as follows: ① total recorded activity time per day (from 24:00 to 24:00 the next day) was not less than 16 hours [37]; ② acceptable non-sleep data required wearing on at least 4 of the 7 days, including at least 1 weekend day, with daily wearing time during wakefulness of not less than 10 hours [38]. The sampling frequency was 80 Hz. Data were downloaded using ActiLife software version 5.6 or higher (ActiGraph LLC) with the low-frequency extension filter in 1-s epochs and reintegrated into 15-s epochs for analysis [39]. Consecutive zero counts lasting 20 minutes or more were defined as non-wear time [40]. After excluding sleep and non-wear time during wakefulness [41], the Evenson (2008) cutpoints were used to classify participants' sedentary behavior and physical activity levels: sedentary behavior (≤25 counts per 15 s), light physical activity (LPA; 25–574 counts per 15 s), moderate physical activity (MPA; 574–1003 counts per 15 s), and vigorous physical activity (VPA; ≥1003 counts per 15 s). Moderate-to-vigorous physical activity (MVPA) was defined as all activities with accelerometer counts ≥574 counts per 15 s [40]. According to the recommendations of Van Hees et al. [42], nighttime sleep duration was calculated using the default algorithm of the GGIR package version 2.0 in R software. In addition, parents or guardians were asked to simultaneously keep sleep logs to cross-validate participants' wake and sleep durations.

Data analysis

Statistical analyses were performed using IBM SPSS 28.0. Continuous variables are presented as means and standard deviations, and categorical variables as frequencies and percentages. Baseline characteristics were summarized by group and compared descriptively using independent-samples t tests, chi-square tests, or Fisher exact tests, as appropriate. Feasibility outcomes were summarized descriptively and evaluated against prespecified criteria. Intervention effects were primarily analyzed according to the intention-to-treat (ITT) principle, including all 48 eligible participants. Because all post-intervention missing data were due to dropout, missing values were imputed using the last observation carried forward (LOCF) method [43]. Repeated-measures analysis of variance was used to examine the effects of time, group, and their interaction on motor

coordination, with partial eta squared (η^2) as the effect size. Statistical significance was set at α = 0.05 (two-tailed). In addition, a per-protocol analysis was conducted among the 42 participants who completed both baseline and post-intervention assessments as a sensitivity analysis.

Results

Randomization results, sample characteristics, and feasibility outcomes

A total of 48 participants were enrolled in this study and randomly assigned at a 1:1 ratio to the intervention group (IG, *N*=24) and the control group (CG, *N*=24). All 48 eligible participants were included in the intention-to-treat analysis, and the 42 participants who completed the post-intervention assessment were included in the per-protocol sensitivity analysis. There were no significant between-group differences in demographic characteristics, anthropometric measures, physical activity levels, sleep duration, or motor coordination ($P_{all} > 0.05$), indicating successful randomization and balanced, comparable baseline characteristics (Table 1).

In terms of feasibility, the study completion rate was 91.7% (22/24) in the intervention group and 83.3% (20/24) in the control group, with no statistically significant between-group difference ($P = 0.666$). In the intervention group, the mean exercise bout completion rate was 94.17% ± 5.80%, the exercise intensity adherence rate was 85.42% (205/240), and the mean monitored exercise intensity was 81.71% ± 1.73%. No adverse events were reported during the intervention. The control group did not receive the intervention; therefore, the relevant feasibility outcomes were not applicable. Overall, baseline characteristics were balanced and comparable between the two groups, and the intervention program performed well in terms of completion, adherence, and safety.

Effects of exercise snacks intervention on motor coordination

As shown in Table 2, a significant group × time interaction effect was observed for motor coordination (MABC-2 total score) ($F_{(1,46)} = 21.87$, $p < 0.001$, $\eta^2p = 0.32$). The improvement in the intervention group (+2.04) was greater than that in the control group (+0.08). At the subdomain level, a significant group × time interaction effect was found for aiming and catching ($F_{(1,46)} = 20.49$, $p < 0.001$, $\eta^2p = 0.31$), with a greater improvement in the intervention group (+1.33) than in the control group (+0.17); a significant group × time interaction effect was also observed for balance ($F_{(1,46)} = 5.53$, $p = 0.023$, $\eta^2p = 0.11$), with a greater improvement in the intervention group (+0.50) than in the control group (+0.04); no significant group × time interaction effect was found for manual dexterity ($F_{(1,46)} = 2.50$, $p = 0.121$, $\eta^2p = 0.05$), and the changes in the intervention group (+0.20) and control group (−0.12) were similar. Changes in mean scores are shown in Figure 3.

Feasibility outcomes

The overall study completion rate was 87.5% (42/48), with rates of 91.7% (22/24) in the intervention group and 83.3% (20/24) in the control group, thereby exceeding the prespecified feasibility criterion of 75%. Intervention participants completed a mean of 84.75±5.22 of the 90 prescribed ES bouts, corresponding to a mean exercise-bout completion rate of 94.17%±5.80%. Twenty-three of the 24 intervention participants (95.8%) completed at least 72 bouts, exceeding the criterion that at least two-thirds of participants complete at least 80% of the prescribed bouts. Heart-rate data were obtained for all 240 planned participant-week monitoring occasions. The mean

monitored exercise intensity was 81.71%±1.73% HRmax, and 205 of the 240 valid monitoring records (85.42%) reached the prescribed intensity range of 80%–90% HRmax, exceeding the prespecified intensity-adherence criterion of 80% (Appendix 1). No intervention-related adverse events, including serious adverse events, were recorded during the 10-week intervention. Overall, all four prespecified feasibility criteria were met. More details are presented in Table 1.

Sensitivity analysis

The results of the per-protocol sensitivity analysis were consistent with those of the intention-to-treat analysis. The group × time interaction effect remained significant for the total motor coordination score, aiming and catching, and balance, but was not significant for fine manual dexterity, supporting the robustness of the main findings. Full results are presented in Supplementary Table S1.

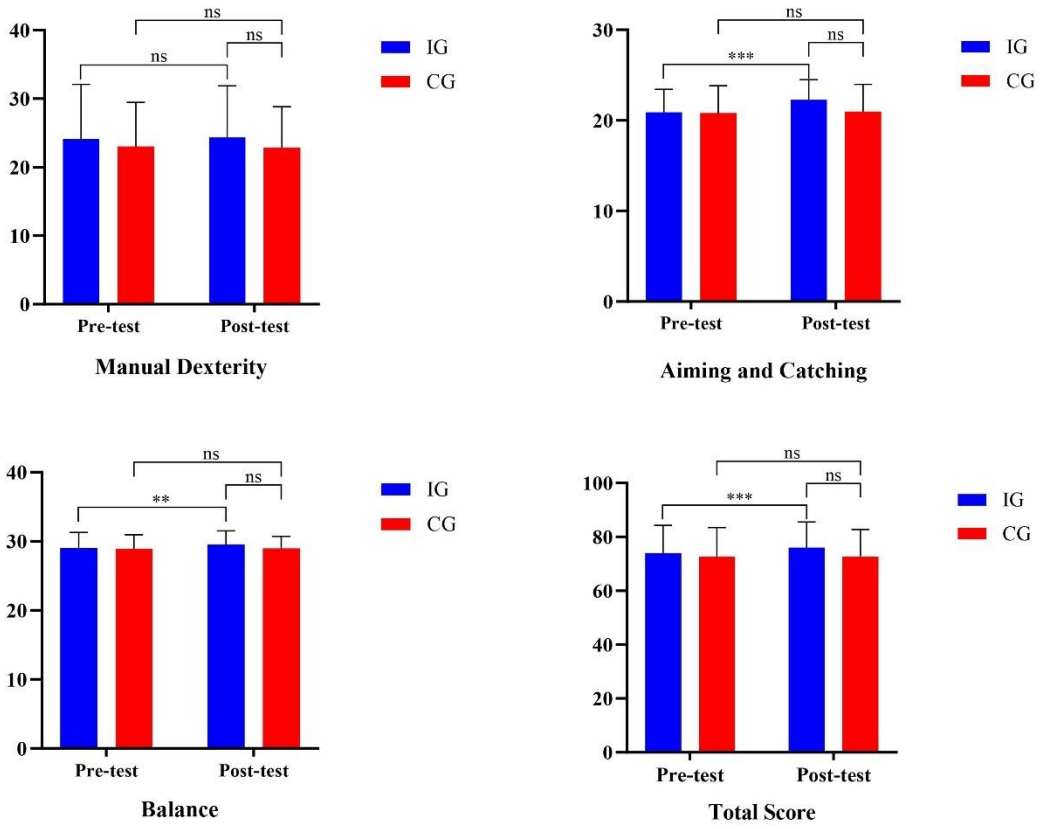


Figure 3. Changes in Mean Scores of Outcome Measures From Pre- to Post-Intervention in the Intervention and Control Groups.

Discussion

Main findings

This pilot randomized controlled trial aimed to evaluate the effects of a 10-week fragmented high-intensity cordless jump rope exercise intervention implemented in both school and home settings on motor coordination in children with obesity. The results indicated that the intervention yielded preliminary improvements in motor coordination among children with obesity, particularly

in aiming and catching, balance, and the MABC-2 total score, whereas improvement in manual dexterity was not yet evident. This finding is generally consistent with the results of previous exercise intervention studies [44–46] and further suggests that different dimensions of motor coordination may exhibit differential responses to specific exercise intervention modalities.

Effects of exercise snacks intervention on motor coordination

In this study, the intervention group showed significant improvements in two dimensions, hand-eye coordination (η^2_p=0.31, large effect) and balance (η^2_p=0.11, moderate effect), whereas manual dexterity did not reach statistical significance (p=0.121). This selective pattern of improvement closely aligns with the movement characteristics of cordless jump rope. Jump rope is essentially a gross motor skill involving multiple joints, encompassing rapid lower-limb take-off and landing, trunk stabilization, and coordinated upper-limb swinging. Its movement pattern is closely related to balance control, rhythm regulation, and temporal organization, and may therefore effectively activate the neuromuscular pathways underlying hand-eye coordination and balance [47]. In contrast, the manual dexterity dimension of the MABC-2 focuses on finger dexterity and fine manipulation ability, which typically require specialized fine motor training to develop; jumping-based exercise alone is unlikely to produce sufficient transfer effects.

From the perspective of motor learning theory, Bernstein's degrees-of-freedom theory posits that in the early stage of learning a new motor skill, learners typically reduce control complexity by "freezing" some mechanical degrees of freedom; as practice continues and the skill becomes more proficient, the relevant degrees of freedom are gradually "released," forming more flexible and coordinated movement control patterns [40, 41]. Children with obesity often have lower levels of moderate-to-vigorous physical activity, and their gross motor coordination, as reflected by neuromuscular performance tests, is also lower, suggesting that multi-joint coordinative control may be affected to some extent in children with obesity [48]. As a highly rhythmic and repetitive form of practice, cordless jump rope may help children repeatedly optimize neuromuscular control strategies within a stable movement pattern, gradually achieving effective integration of degrees of freedom in the lower limbs, trunk, and upper limbs, thereby making movements more fluent and efficient. Although each exercise session lasted only approximately 1 minute in this pilot intervention, the cumulative training volume of 3 sessions per day, 3 days per week, for 10 weeks still provided participants with sufficient frequency of motor practice, reflecting the "short-duration, high-frequency, cumulative effect" characteristics of exercise snacks.

Notably, the effect size for the MABC-2 total score in this study reached a large level (η^2p = 0.32), and the intervention group showed a mean increase of 2.18 points in the total score. This result is consistent with the findings of Zhang et al. [49], who reported significant improvements in children's MABC-2 total scores after a 12-week structured physical activity intervention, suggesting that exercise snacks may likewise have the potential to improve overall motor coordination in children. This result is also consistent with the conclusions of the systematic review by Han et al. [50], further supporting the effectiveness of exercise interventions in improving MC in children with overweight/obesity and providing the first empirical evidence for cordless jump rope as an exercise

snacks intervention modality.

In summary, exercise snacks intervention significantly improved gross motor coordination (hand-eye coordination and balance) in children with obesity, with substantial effect sizes. Because this modality has low requirements for space and equipment and is flexible to implement, it has strong potential for dissemination and is suitable for school physical education and family health promotion settings. Future studies could incorporate fine motor tasks into exercise snacks programs to explore optimized intervention strategies for achieving simultaneous improvements across multiple dimensions of coordination.

Strengths and limitations

This study has several strengths. First, a randomized controlled design was employed, with strict adherence to inclusion and exclusion criteria and randomization procedures, effectively controlling for selection bias; baseline characteristics were balanced and comparable between the two groups, indicating high internal validity. Second, the study focused on children with obesity, addressing the gap in evidence regarding exercise snacks interventions in this population. Third, the intervention was implemented in a dual school–home setting, using cordless jump rope as the modality, which has low requirements for space and equipment, good ecological validity, and strong potential for dissemination. This study also has several limitations. First, the sample size was relatively small (N=42 in the per-protocol analysis), which may have resulted in insufficient statistical power for some outcomes (e.g., manual dexterity, p=0.08); future studies should further increase the sample size. Second, the 10-week intervention period may be insufficient for improving fine motor skills, and changes in such abilities may require a longer intervention duration. Third, daily diet and other covariates were not strictly controlled, which may have influenced the results to some extent. In addition, no long-term follow-up was conducted, and the sustainability of the intervention effects remains to be verified in future studies.

Conclusions

This randomized controlled trial demonstrated that a 10-week exercise snacks intervention significantly improved overall motor coordination in children with obesity, with stable and substantial improvements particularly in aiming and catching and balance. Characterized by “short duration, high frequency, and integration into daily life,” this modality provides a time-efficient, setting-flexible, and practical intervention pathway for promoting motor competence in children with obesity. However, the intervention effects were markedly dimension-specific: improvements in fine motor skills were not yet sufficient. This suggests that improvements in motor coordination are not driven solely by accumulated exercise volume, but may depend on the neuromuscular compatibility between intervention content and specific motor dimensions.

These findings have important implications for future intervention design: in addition to jumping-based gross motor training, fine motor tasks should be deliberately incorporated to construct a composite exercise strategy that promotes the coordinated development of gross and fine motor skills, thereby achieving comprehensive optimization of motor coordination in children with obesity. Overall, this study provides preliminary empirical support for the application of exercise

snacks in the field of child health promotion and promotes a shift in motor coordination interventions from a "dose-oriented" mindset to a "content-fit" mindset, laying a theoretical and empirical foundation for developing more precise and multidimensional exercise intervention programs for children with obesity.

Table 1 Baseline characteristics and feasibility outcomes of the study sample

Variable	IG (*N*=24)	CG (*N*=24)	Total (*N*=48)	t/χ^2	*p* value
Age (years)	9.25±1.57	9.21±1.59	9.23±1.56	0.09	0.927
Sex, n (%)					
Male	13 (54.2)	14 (58.3)	27 (56.3)	0.09	0.771
Female	11 (45.8)	10 (41.7)	21 (43.8)		
Family Economic Status, n (%)					
Low	3 (12.5)	4 (16.7)	7 (14.6)	0.36	0.830
Medium	14 (58.3)	12 (50.0)	26 (54.2)		
High	7 (29.2)	8 (33.3)	15 (31.3)		
BMI, kg/m²	24.91±2.45	24.48±2.30	24.69±2.36	0.63	0.527
LPA (min/day)	216.51±45.64	221.15±45.79	218.83±45.29	-0.35	0.727
MVPA (min/day)	43.05±13.53	41.32±9.39	42.18±11.55	0.52	0.608
Sedentary Behavior (min/day)	639.77±65.85	633.58±55.76	636.68±60.44	0.35	0.727
Sleep Duration (min/day)	540.67±33.67	543.96±32.02	542.31±32.54	0.35	0.730
Feasibility outcomes					
Study completion[1]	22/24 (91.7%)	20/24 (83.3%)	42/48 (87.5%)	0.19	0.666
Mean exercise-bout completion[2]	84.75±5.22 (94.17%±5.80%)	NA	NA		NA
Exercise intensity adherence[3]	205/240 (85.42%)	NA	NA		NA
Mean monitored exercise intensity[3]	81.71%±1.73%	NA	NA		NA
Exercise safety[4]	0 adverse event	NA	NA		NA

Note. BMI=body mass index; LPA = light-intensity physical activity; MVPA = moderate-to-vigorous physical activity; NA=not applicable; [1]Feasibility criterion was met when more than 75% of randomized participants completed the post-intervention assessment. [2]Exercise-bout completion was calculated relative to the 90 prescribed high-intensity exercise bouts. The feasibility criterion was met when at least two-thirds of intervention participants completed at least 80% of the prescribed bouts ($\geqslant$72 of 90 bouts). [3] Heart-rate intensity adherence was calculated as the proportion of valid participant-week monitoring records in which the high-intensity segment reached 80%–90% of estimated HRmax. The feasibility criterion was met when at least 80% of valid monitored segments achieved the prescribed intensity range. Mean monitored exercise intensity represents the average percentage of estimated HRmax across all valid participant-week records. [4]Safety was considered acceptable when no serious intervention-related adverse events occurred during the 10-week intervention.

Table 2. Repeated-measures ANOVA for the effects of exercise snacks intervention on motor coordination in children with obesity under the intention-to-treat analysis

Variables	Time point	IG ($N = 24$)	CG ($N = 24$)	Group × time interaction			Time effect			Group effect		
MABC-2 Score		Mean (SD)		*F(1, 46)*	*p*	*η²p*	*F(1, 46)*	*p*	*η²p*	*F(1, 46)*	*p*	*η²p*
Manual Dexterity	T1	24.13±8.00	23.00±6.49	2.50	0.121	0.05	0.16	0.695	0.003	0.40	0.528	0.01
	T2	24.33±7.55	22.88±5.97									
Aiming and Catching	T1	20.92±2.52	20.79±3.04	20.49	**<0.001**	0.31	33.87	**<0.001**	0.42	0.83	0.366	0.02
	T2	22.25±2.23	20.96±3.03									
Balance	T1	29.00±2.27	28.92±2.02	5.53	**0.023**	0.11	7.73	**0.008**	0.14	0.30	0.589	0.01
	T2	29.50±2.00	28.96±1.76									
Total Score	T1	74.04±10.27	72.71±10.73	21.87	**<0.001**	0.32	25.75	**<0.001**	0.36	0.63	0.432	0.01
	T2	76.08±9.44	72.79±10.0									

Note: SD = standard deviation; IG = intervention group; CG = control group. T1=baseline assessment; T2=post-intervention assessment. MABC-2=Movement Assessment Battery for Children-Second Edition.

Declarations

Abbreviations

MC: motor coordination; HRmax: maximum heart rate; BMI: body mass index; MABC-2: Movement Assessment Battery for Children–Second Edition; MVPA: moderate-to-vigorous physical activity; ITT: intention-to-treat; LOCF: last observation carried forward.

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments, or with comparable ethical standards. The study protocol was approved by the Medical Research Ethics Committee of Shenzhen University (Ref. No. PN-202400005). Written informed consent was obtained from the children's parents and/or caregivers before the study commenced.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to the privacy of the participants and restrictions imposed by the ethics committee, but are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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Authors' contributions

Conceptualization, Lin Zhou, Jiecai Zheng, and Liu Mu; methodology, Yuxi Shi and Chenchen Wang; validation, Liu Mu and Chenchen Wang; formal analysis, Chenchen Wang and Yuxi Shi; investigation, Lin Zhou, Jiecai Zheng, Jiayu Chen, and Wei Liang; resources, Yuxi Shi and Lin Zhou; data curation, Yuxi Shi and Chenchen Wang; writing—original draft preparation, Yuxi Shi and Liu Mu; writing—review and editing, Liu Mu and Chenchen Wang; supervision, Liu Mu; project

administration, Liu Mu; funding acquisition, Lin Zhou. All authors have read and agreed to the published version of the manuscript.

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Trial registration

The present study formed part of a larger research project that was prospectively registered with the Chinese Clinical Trial Registry (ChiCTR2200066143).

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