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Research article

Comparing The Effects of Small-Sided Handball Games and High-Intensity Interval Training on The Physical Health and Fitness of Untrained Individuals: A 16-Week Randomized Controlled Study

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Abstract

This study aimed to compare the effects of small-sided games (SSG) and high-intensity interval training (HIIT) on the physical health and fitness of sedentary, untrained young adults. A 16-week randomized controlled trial was conducted with 90 participants (mean age 19.82 ± 0.66 years; 45 males and 45 females), who were randomly assigned in a 1:1:1 ratio to either the SSG group, the HIIT group, or a non-training control group (CG). Each group included 30 participants, and all participants completed the intervention. All interventions were performed three times per week. The SSG group participated in 4v4 or 6v6 handball games, while the HIIT group completed 30 - 30 (30 s sprint/30 s active recovery) or 40 - 20 (40 s sprint/20 s active recovery) protocols on an outdoor rubber track at 80 - 85% of their maximum heart rate (HRmax). Measured outcomes included physiological indicators (body weight, body mass index [BMI], systolic/diastolic blood pressure [SBP/DBP], and resting heart rate [RHR]) and fitness indicators (grip strength, one-repetition maximum squat [1RM], 20-meter multistage fitness test [20 m MFT] performance, and maximal oxygen uptake [VO_2max]). Baseline characteristics were well balanced across groups (standardized mean differences < 0.50). After 16 weeks, both SSG and HIIT significantly reduced body weight, BMI, SBP, DBP, and RHR ($p < 0.01$), while significantly improving 1RM squat, 20 m MFT performance, and VO_2max ($p < 0.01$). In contrast, the CG group showed significant decreases in SBP, left-hand grip strength, and 1RM squat ($p < 0.05$). Between-group analyses indicated that SSG and HIIT produced substantially greater improvements than the CG in cardiometabolic outcomes, for example, VO_2max increased by approximately 7 $mL \cdot kg^{-1} \cdot min^{-1}$ in both training groups, whereas it showed little or no change in the CG. For body weight and BMI, only body weight differed significantly between the SSG and CG groups ($p < 0.05$). No significant between-group differences were observed in grip strength ($p > 0.05$), and no significant differences were found between the SSG and HIIT groups across any indicators (all $p > 0.05$). In conclusion, both SSG and HIIT effectively improved physical health and fitness in sedentary young adults. SSG may be more suitable for individuals seeking an enjoyable, game-based approach that supports upper limb strength development, while HIIT may be preferable for those aiming to enhance aerobic fitness efficiently. Because SSG offers an enjoyable, socially interactive, game-based format and HIIT provides a time-efficient, highly structured format, both modalities may promote sustained participation beyond initial adoption in previously inactive young adults.

Key words: Handball, conditioned games, physical exercise, health, aerobic exercise.

Introduction

The widespread shift towards sedentary modern lifestyles has become a global public health concern. Globally, over one-third of adults fail to meet the World Health Organization's (WHO) minimum physical activity recommendation of at least 150 minutes of moderate-intensity exercise per week (Organization, 2019). Alarmingly, the prevalence of physical inactivity continues to rise in approximately half of all countries and two-thirds of regions worldwide. Substantial evidence links sedentary behavior to increased risks of obesity, type 2 diabetes, cardiovascular diseases, and various causes of mortality, including specific non-communicable diseases such as breast and colon cancer (Ekelund et al., 2019; Lee et al., 2012). Even before the onset of clinical disease, prolonged sitting can trigger a decline in physiological function, manifesting as muscle atrophy, decreased basal metabolic rate, reduced maximal oxygen uptake (VO_2max), and impaired balance (Katzmarzyk et al., 2022). These changes not only diminish quality of life but may also accelerate the aging process (Pinto et al., 2023). Therefore, intervening during this pre-pathological window is critical for preventing chronic diseases and maintaining health (Bull et al., 2020). Within the behavioral epidemiology framework (Sallis et al. 2000), which conceptualizes research on health behaviors across phases from establishing behavior–health links to evaluating interventions and translating them into practice exercise-based interventions are situated in the later "intervention" and "translation" phases as strategy-level actions aimed at modifying the proximal behavioral risk of physical inactivity.

The health benefits of physical activity are well-established (Warburton, 2006). However, traditional aerobic exercises like jogging and cycling, despite their efficacy, often suffer from monotony and a lack of interactivity. This frequently leads to mental fatigue and poor long-term adherence, limiting their practical effectiveness (Warburton, 2006). In response, researchers have explored more engaging and sustainable alternatives. High-Intensity Interval Training (HIIT) and team-based training have emerged as promising solutions, demonstrating potential superiority over traditional aerobic exercise in promoting physical and

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mental health (Bělka et al., 2023; Castagna et al., 2018; Engel et al., 2018; Santos et al., 2023; Vukadinović Jurišić et al., 2021).

HIIT is characterized by alternating short bursts of high-intensity exercise with periods of low-intensity recovery or rest. Extensive research demonstrates that HIIT significantly improves maximal oxygen uptake (VO_2max) and key risk factors for metabolic syndrome, including reduced blood pressure, enhanced insulin sensitivity, and decreased body fat accumulation. These benefits are consistent across diverse populations, including healthy individuals and those with chronic diseases (Batacan et al., 2017; Engel et al., 2018; Lazić et al., 2024; Poon et al., 2024; Ramos et al., 2015; Santos et al., 2023). Furthermore, HIIT exerts positive effects on the neuromuscular system, enhancing muscle strength and endurance, promoting fat oxidation, and improving mitochondrial biogenesis and function, thereby optimizing metabolic regulation (Hung et al., 2025; Poon et al., 2024).

Similarly, small-sided games (SSG), such as recreational handball, share physiological characteristics with HIIT and offer a potent alternative for health promotion (Bělka et al., 2023; Gardasevic et al., 2023). Unlike individualized training, handball features a dynamic tempo with frequent transitions between offense and defense. Participants repeatedly perform high-intensity actions—accelerations, decelerations, sudden stops, directional changes, and shots—within brief time frames, creating a natural pattern of high-intensity intervals (Buchheit et al., 2009; Castagna et al., 2018; Delextrat and Martinez, 2014). Studies show that heart rate during handball can be sustained above 85% of maximum heart rate (HRmax), leading to substantial improvements in cardiorespiratory endurance (Hornstrup et al., 2019). Beyond cardiovascular benefits, it also enhances overall muscle strength, movement coordination, and energy metabolism (Fristrup et al., 2020; Hornstrup et al., 2019; Hornstrup et al., 2020; Hornstrup et al., 2018; Pereira et al., 2021; Póvoas et al., 2018; Póvoas et al., 2017; Stojiljković et al., 2020). Importantly, SSG may provide social and affective affordances that distinguish them from traditional exercise modalities. Their interactive and cooperative–competitive structure possibly promotes social bonding, shared goals, and mutual feedback, which can increase enjoyment, motivation, and adherence (Andersen et al., 2019). The playful nature of game-based activities can promote positive affect, reduces perceived exertion, and may enhance long-term engagement in physical activity (Bruun et al., 2014).

Critically, the social structure and shared objectives of team sports like recreational handball can stimulate the release of pleasure-related neurohormones, alleviate perceived exertion, and enhance exercise enjoyment (Castagna et al., 2018; Madsen et al., 2019). This sociopsychological dimension may make SSG more effective than individualized training in boosting motivation and long-term adherence among sedentary populations, facilitating not only short-term exercise persistence but also a sustainable shift toward a healthier lifestyle (Castagna et al., 2018). While HIIT and SSG impose comparable high-intensity physiological demands capable of improving cardiometabolic and neuromuscular health, they likely differ in their psychosocial profiles. From a self- determination theory perspective, HIIT's highly strenuous and prescriptive structure may predominantly evoke controlled forms of motivation, especially in individuals with low baseline fitness (Burford et al. 2022). In contrast, SSG embeds similar physiological loading within a likely socially interactive, play-based environment that can enhance enjoyment (Selmi et al., 2020).

In other team sports, recreational soccer consistently improves VO_2max, lowers blood pressure, and favorably alters body composition in untrained adults (Krustrup et al., 2009) Among hypertensive middle-aged men, six months of recreational soccer produced meaningful aerobic and blood-pressure improvements versus standard care (Krustrup et al., 2013). Meta-analytic evidence shows recreational football yields broad cardiometabolic benefits, including reductions in resting heart rate, fat mass, LDL cholesterol, and blood pressure (Milanović et al., 2019). Street or small-sided basketball training over 12 weeks improves health-related fitness and risk profiles in previously inactive adults (Randers et al., 2018). In older men, community floorball programs improve HbA1c, resting heart rate, and body composition, with signals for bone health benefits (Pedersen and Bangsbo, 2025). Overall, systematic reviews conclude that recreational team sports such as handball, floorball, basketball, touch rugby, futsal, and volleyball are effective modalities for improving cardiorespiratory fitness and multiple health parameters in inactive adults (Castagna et al., 2020).

Previous randomized trials have shown that recreational handball–based SSG can improve mechanical muscle function, body composition, bone health, and cardiometabolic risk markers in untrained young adults when compared with inactive control groups (Fristrup et al., 2020; Hornstrup et al. 2019). Moreover, HIIT is also able to improve such improvements (Poon et al., 2024). However, these investigations have typically examined SSG or HIIT in isolation, focused on sport-specific performance in trained athletes, or used other team sports rather than handball. To our knowledge, no trial has directly compared handball-based SSG and running-based HIIT in sedentary, previously untrained young women and men using a matched training dose and a set of health- and fitness-related outcomes, which constitutes the main novelty of the present study.

To address this gap, the present study conducted an intervention experiment comparing the effects of HIIT and SSG training on physical function in sedentary, untrained individuals. We hypothesized that both training methods would produce greater improvements than the control group. We expected HIIT to elicit greater increases in aerobic capacity because its structured and sustained high-intensity bouts are known to promote central cardiovascular adaptations (e.g., increased stroke volume), peripheral adaptations (e.g., enhanced mitochondrial density and oxidative enzyme activity), and improved oxygen transport efficiency (Gibala and MacInnis, 2022). In contrast, we expected SSG to provide benefits for neuromuscular performance, as gameplay involves frequent accelerations, decelerations, directional changes, and repeated sprint-like actions that challenge mechanical power output (Rebelo et

al., 2016). Additionally, because SSG integrates social interaction and affective engagement, we anticipated that it could enhance motivation and reduce perceived exertion (Selmi et al., 2020). In line with this rationale, the primary endpoint of the study is the change in maximal oxygen uptake (VO_2max), with secondary endpoints including cardiometabolic indicators (e.g., systolic blood pressure (SBP), diastolic blood pressure (DBP), resting heart rate), body composition, and neuromuscular performance measures.

Methods

Study design

This study was designed as a randomized controlled trial. Participants were randomly assigned in a 1:1:1 ratio to one of three groups: the small-sided game (SSG) group (n = 30), the high-intensity interval training (HIIT) group (n = 30), or the control group (CG) (n = 30), which did not take part in any structured training program (Figure 1).

The randomization sequence was generated using Research Randomizer, a free web-based tool that allows specification of block sizes and stratification procedures. Permuted blocks of size 3 and 6 were created within sex-stratified sampling frames, ensuring balanced allocation across the three groups for both male and female participants. The independent researcher retained exclusive control of the randomization list, which was not accessible to the recruitment team at any stage. Allocation concealment was ensured by transferring the sequence to sealed, opaque, sequentially numbered envelopes, prepared and stored by a third party not involved in enrollment or assessment. Envelopes were opened only after a participant had completed baseline testing.

Recruitment strategies included oral invitations, distribution of information letters, and social media advertisements targeting university students. Eligibility criteria required participants to be free from acute or chronic illness, free from injury or ongoing treatment, and able to adhere to study requirements with a compliance rate above 85% in the intervention groups. Additionally, participants were required to attend all assessment sessions. All participants provided written informed consent after receiving a full explanation of study procedures and potential risks.

Ethical aspects

This study complied with the ethical standards outlined in the Declaration of Helsinki for medical research involving human participants. All participants were fully informed about the research design and provided written informed consent, which explicitly stated their right to withdraw from the study at any time without penalty. No financial compensation was offered for participation. Signed consent forms were securely stored, with digital copies encrypted on a protected server and physical copies kept in a locked facility. Ethical approval was obtained from the Ethics Committee of Hunan Institute of Mechanical and Electrical Technology and Vocational Education (Approval Number: 2025017; February 17, 2025). To protect participant privacy and safety, all data were de-identified and analyzed using unique codes. A safety monitoring system was implemented to record and report any adverse events (e.g., muscle strains) to the ethics committee. No pre-defined stopping rules were established, as the interventions were considered low-risk.

Participants

Statistical power was assessed post hoc in G*Power 3.1 for an F-test (ANOVA: repeated measures, within–between

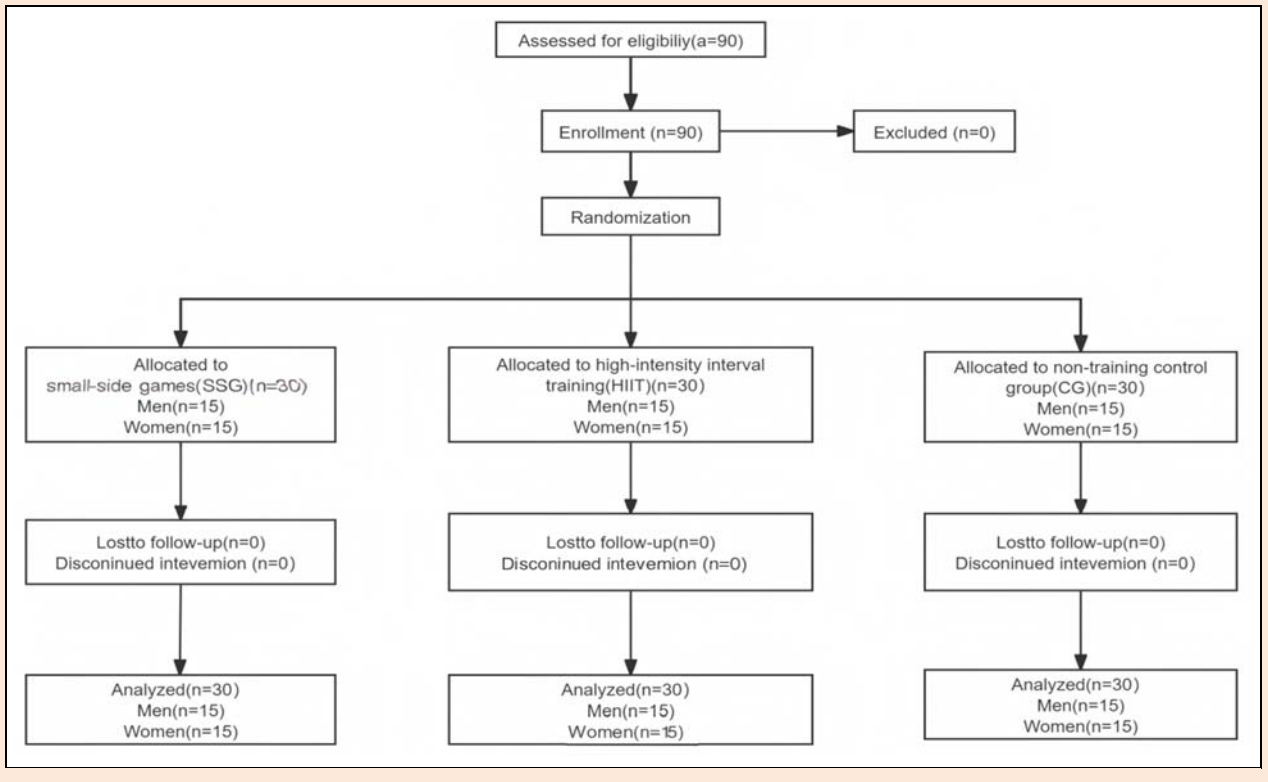

Figure 1. Flowchart. SSG: small-side games; HIIT: High-intensity interval training; CG: control group.

Table 1. General descriptive parameters.

	SSG (n = 30)		HIIT (n = 30)		CG (n = 30)		Total
	Men	Woman	Men	Woman	Men	Woman	
Age	19.73 ± 0.59	19.60 ± 0.74	20.00 ± 0.54	19.47 ± 0.64	20.00 ± 0.66	20.13 ± 0.64	19.82 ± 0.66
Height (m)	1.81 ± 0.06	1.68 ± 0.05	1.78 ± 0.06	1.67 ± 0.07	1.79 ± 0.06	1.67 ± 0.04	1.73 ± 0.08
Weight (kg)	74.93 ± 10.96	64.05 ± 9.28	75.00 ± 10.73	65.30 ± 8.88	75.52 ± 7.81	63.87 ± 8.89	69.78 ± 10.7
BMI (kg/m²)	22.98 ± 2.96	22.73 ± 3.02	23.60 ± 3.48	23.53 ± 2.91	23.57 ± 1.61	22.98 ± 2.93	23.23 ± 2.82

SSG: small-sided games; HIIT: high-intensity interval training; CG: control group; BMI: body mass index.

interaction) with f = 0.20, α = 0.05, N = 90 (30/group), 3 groups, 3 time points, r = 0.50, and ε = 1.0, yielding 1 – β = 0.972. The choice of f = 0.20 is grounded in primary RCTs on untrained/low-active adults showing small-to-moderate standardized gains in cardiorespiratory fitness over 8–12 weeks: (i) in healthy untrained men randomized to recreational soccer vs running vs control, absolute VO_2max rose ~14% in the soccer group (Δ = +418 ± 65 mL·min⁻¹) with a reported within-group effect size d ≈ 0.62 (and relative VO_2max ES d ≈ 1.20, partly reflecting weight loss) over 12 weeks, compared with no improvement in controls, supporting at least moderate pre–post effects in this population (Milanović et al., 2015); (ii) in healthy men performing <150 min·wk⁻¹ of activity, an 8-week HIIT program increased VO_2max from 39.2 ± 6.0 to 42.7 ± 6.0 mL·kg⁻¹·min⁻¹ (Δ = +3.5 mL·kg⁻¹·min⁻¹, ~9.4%), corresponding to an approximate within-group Cohen's d ≈ 0.58 (3.5/6.0), while not outperforming MICT between groups—again indicating moderate pre–post gains in low-active adults (Arboleda-Serna et al., 2019). The data justify a conservative small-to-moderate interaction assumption (f = 0.20) for our repeated-measures design, making the observed power (0.972) a realistic estimate for detecting the hypothesized group × time effects.

The sample had a mean age of 19.82 ± 0.66 years, mean height of 1.73 ± 0.08 m, and mean body weight of 69.04 ± 11.21 kg. On average, participants engaged in less than 90 minutes of physical activity per week, consisting primarily of moderate- to low-intensity exercise, which met the inclusion requirements for this study. Following random allocation, the baseline characteristics of each group are presented in Table 1.

Monitoring of physical activity

To control for potential confounding effects of spontaneous physical activity outside the intervention, participants' general physical activity levels were monitored throughout the 16-week study period using the International Physical Activity Questionnaire – Short Form (IPAQ-SF) (Craig et al., 2003). Assessments were administered at 4-week intervals, resulting in four measurements: baseline (T0), 4 weeks (T1), 8 weeks (T2), 12 weeks (T3), and 16 weeks (T4). The IPAQ-SF has showed acceptable reliability and validity in adults, with test–retest reliability coefficients clustering around 0.8 across 12 countries and fair criterion validity against accelerometry (median Spearman's ρ ≈ 0.30) in adults aged 18 - 65 years (Craig et al., 2003). To ensure data quality, all surveys were administered by trained researchers via an online platform. They provided standardized oral instructions emphasizing the "past 7 days" recall window and reviewed responses immediately to minimize missing or ambiguous data (e.g., unreported duration). Total weekly physical activity was expressed as MET-minutes/week, calculated by multiplying the weekly duration of high-intensity (8 METs), moderate-intensity (4 METs), and walking (3.3 METs) activities by their respective MET values and summing the products. Following IPAQ guidelines, total weekly activity time was truncated at 960 minutes to mitigate over-reporting(Craig et al., 2003).

Throughout the entire trial process, the compliance rates of both the SSG group (small-sided games) and the HIIT group reached high standards. Compliance was precisely defined by three indicators: (1) attendance rate (the percentage of the number of scheduled training sessions attended); (2) training time within the target heart rate range (the time spent within the 80%-85% range of the maximum heart rate in each training session); (3) adherence to the RPE threshold (the proportion of training sessions reaching a score of 6-9). The compliance rate of the SSG group was 92.5% ± 3.2%, with a 95% confidence interval of [90.1%, 94.9%]; the compliance rate of the HIIT group was 91.8% ± 4.1%, with a 95% confidence interval of [89.2%, 94.4%].

The attendance status of each training session is verified through the registration form for each training session. For the analysis of those who did not participate in the training, the intention-to-treat (ITT) method was adopted, and the missing heart rate/RPE data were filled in through multiple imputations (based on the observed training patterns) (Schulz et al., 2010). Flowchart (Figure 1) confirmed that no participants dropped out (all randomized participants completed the trial). In addition, no additional specific encouragement measures or engagement strategies were implemented; It all depends on the willingness of the participants to invest in the training.

Training intervention

This training intervention was carried out three times a week, on Monday, Wednesday and Friday. The team training sessions began at 5:30 p.m. During the training period, the average temperature was 26.1 ± 3.4 degrees Celsius and the relative humidity was 53.2 ± 4.2%. After following the standard warm-up procedure (including 5 minutes of moderate-intensity running at one's own pace, 5 minutes of dynamic lower body stretching, and 5 minutes of lower body reaction training), the players were divided into groups and began the training process (Table 2). There were no differences in the amount, intensity and frequency of the training, which was an important factor when comparing the effects of these three groups.

Small-Sided Games (SSG)

The SSG intervention consisted of two formats: 4v4 and 6v6. The 4v4 format was played on a 25 × 20 m pitch and comprised four 4-minute bouts, each separated by 3 minutes of passive rest, for a total exercise time of 16 minutes. The 6v6 format was conducted on a 40 × 20 m pitch and consisted of two 8-minute bouts with a 5-minute

rest interval, also totaling 16 minutes of exercise. Official handballs appropriate to participants' sex were used, with standard 2 × 3 m goals. To ensure continuous play, multiple spare balls were positioned around the court perimeter for rapid restarts. Coach involvement was deliberately minimized, restricted to organizing player substitutions and offering general motivational prompts (e.g., "press"), without providing technical or tactical feedback. A rule constraint was applied whereby the attacking team was required to attempt a shot on goal within 20 seconds of gaining possession. The specific training parameters are detailed in Table 2.

High-Intensity Interval Training (HIIT)

High-intensity interval training (HIIT) was carried out on an outdoor rubber track and implemented using two protocols that differed primarily in sprint duration. In the 30 - 30 protocol, participants completed 30 seconds of sprinting at 80 - 85% Hrmax, followed by 30 seconds of active recovery at a walking pace of 4 km·h^{-1}. In the 40 - 20 protocol, participants performed 40 seconds of sprinting at the same relative intensity, followed by 20 seconds of active recovery at 4 km·h^{-1}.

Both protocols followed an identical structure consisting of 4 sets of 4 repetitions with 3 minutes of passive rest between sets, resulting in a total work duration of 16 minutes. Training intensity was prescribed individually based on each participant's maximal heart rate (HRmax), which was obtained from a maximal graded exercise test using the Bruce treadmill protocol performed until volitional exhaustion. The Bruce protocol is widely used and considered valid and safe for estimating HRmax in healthy sedentary adults, as it produces a progressive workload capable of reliably eliciting maximal cardiovascular responses (Beltz et al. 2016). Because heart rate exhibits a lag at the onset of exercise, sprint intensity was initially guided by a pre-determined target speed. Heart rate feedback was subsequently used to fine-tune sprint velocity, ensuring participants remained within the prescribed range of 80 - 85% Hrmax throughout the sprint intervals. The specific training parameters are provided in Table 2.

Exercise intensity and exertion were monitored using both heart rate (HR) and the rating of perceived exertion (RPE). HR was selected as an objective marker of cardiovascular strain, reflecting the physiological response to exercise. However, HR can be affected by hydration status, fatigue, and environmental conditions, and therefore may not fully represent subjective effort. To address this limitation, RPE was also recorded, providing complementary insight into participants' perceived exertion during the training sessions (Achten and Jeukendrup, 2003). In contrast, the subjective exertion score is evaluated based on an individual's subjective perception of exercise intensity, and can comprehensively reflect factors such as the requirements of the exercise mode (such as mechanical work or total movement distance) (Skatrud-Mickelson et al., 2011). By using both heart rate monitoring (HR) and Rating of Perceived Exertion (RPE) simultaneously, we can more comprehensively assess the overall load borne by the body during exercise. During the training process,

Table 2. Description of the handball small-sided games (SSG) and high-intensity interval training (HIIT) training programs.

Period of time	Group SSG	Group HIIT
Week 1 -Week 4	SHG format:4v4 Pitch Size:25×20 m Goal size: 2×3 m Coach encouragement: Yes Sets:4 Work: 4min Rest between sets: Rest: 3min	Sets: 4 Repetitions: 4 Work: 30s Active recovery: 30s Work intensity: 80%-85% Hrmax Recovery intensity: 4km/h Rest between sets: 3min
Week 5-Week 8	SHG format:6v6 Pitch Size:20x40m Goal size: 2×3 m Coach encouragement: Yes Sets:2 Work: 8min Rest:5 min	Sets: 4 Repetitions: 4 Work: 40s Active recovery: 20s Work intensity: 80%-85% Hrmax Recovery intensity: 4km/h Rest between sets: 3min
Week 9-Week 12	SHG format:4v4 Pitch Size:25x20m Goal size: 2×3 m Coach encouragement: Yes Sets:4 Work: 4min Rest: 3min	Sets: 4 Repetitions: 4 Work: 30s Active recovery: 30s Work intensity:80%-85% Hrmax Recovery intensity: 4km/h Rest between sets: 3min
Week 13 – Week 16	SHG format:6v6 Pitch Size:20x40m Coach encouragement: Yes Goal size: 2×3 m Sets:2 Work: 8min Rest: 5min	Sets: 4 Repetitions: 4 Work: 40s Active recovery: 20s Work intensity:80%-85% Hrmax Recovery intensity: 4km/h Rest between sets: 3min

we employed the Borg CR10 scale to assess the participants' exercise intensity, and immediately recorded their individual scores after each training session.

The Borg CR10 scale is an effective scale for assessing perceived fatigue, capable of distinguishing between various levels of difficulty in motor tasks based on their complexity, intensity, and level of resistance. This scale is applicable to different groups and has been widely used in the assessment of cardiopulmonary function and muscle strength in sports (Williams, 2017). Recent work using the CR10 showed excellent reliability (ICC = 0.92) and strong associations between session-RPE and objective training load indices ($r \geq 0.70$) in recreationally trained and trained individuals, supporting its use as a valid indicator of internal training load (van der Zwaard et al., 2023). Additionally, the heart rate can more objectively reflect the intensity of the exercise. In this study, we used a heart rate monitor based on telemetry technology (Polar RS400, Kemijärvi, Finland) to continuously monitor heart rate at a frequency of once per second. During training, athletes were allowed to replenish water at different time periods to ensure adequate water intake, which is applicable to all the exercise scenarios mentioned in the article(Achten and Jeukendrup, 2003).

HR data were continuously recorded throughout each session (1 Hz), and the corresponding RPE score was obtained immediately at the end of each training session. HR data were then segmented into sets, and the mean HR for each set and for the full session was calculated. RPE values therefore represent a session-level perceptual response that corresponds temporally to the HR data averaged across the same session.

Measurement procedures

The evaluations were conducted by three professional trainers. Testing sessions began each day at 5:00 p.m., with the ambient temperature maintained between 23°C and 28°C. To enhance data reliability, participants were instructed to maintain consistent daily dietary intake throughout the testing period. Prior to each assessment, the procedures were explained in detail by the coaches, and participants were randomly divided into three groups for testing.

The assessment protocol spanned three consecutive days. On the first day, measurements included resting heart rate, blood pressure, height, weight, and body mass index (BMI). All physiological assessments were performed in a quiet, controlled environment. On the second day, participants completed handgrip strength testing and the one-repetition maximum (1RM) assessment. On the third day, cardiorespiratory fitness was evaluated using the 20-meter multi-stage shuttle run test (20m MFT).

Blood pressure and resting heart rate

Resting blood pressure and heart rate were assessed at three time points: baseline (prior to the intervention), week 8, and week 16. All measurements were conducted at approximately 09:00 a.m. on non-training days to minimize the acute influence of exercise and account for diurnal variation. Following the standard operating procedures outlined in the Experimental Guidelines for Exercise Physiology, participants were instructed to fast for at least 2 hours and to avoid water intake for 1 hour before testing. Upon arrival at the laboratory, they rested quietly in a seated position for 15 minutes before measurements began.

Assessments were carried out by the same trained researcher using a calibrated electronic sphygmomanometer (Omron HEM-7136, Omron Healthcare, Kyoto, Japan), which has been validated for accuracy(Kang et al., 2016). Cuff size was selected according to each participant's mid-arm circumference. With the right arm supported at heart level, three consecutive readings were taken at 1-minute intervals. The final two measurements were used for analysis to enhance precision and reliability. The same standardized protocol was applied to determine resting heart rate.

Handgrip strength measurement

Handgrip strength was measured in accordance with standardized procedures outlined in the Manual of Motor Function Assessment and Testing. Participants were seated on an adjustable chair, with the knee joint flexed at 90°, the shoulder in a neutral position, the elbow flexed at 90°, and the forearm in a neutral position resting on the armrest. An electronic grip dynamometer (TKK 5101 Grip-D, Takey, Tokyo, Japan), calibrated prior to testing, was used for all assessments. The handle distance was individually adjusted so that the distal interphalangeal joint of the index finger was aligned parallel to the handle, ensuring consistent grip mechanics.

Measurements were performed alternately with the left and right hands. To familiarize participants with the device, two practice trials were conducted before the formal assessment. Subsequently, three maximal-effort trials were performed for each hand, separated by 60-second rest intervals to minimize fatigue. The peak force (kg) from the three attempts was recorded as the final score for each hand. Throughout the test, participants were instructed to keep the wrist in a neutral position and to avoid compensatory movements such as trunk rotation or body sway; any trial with visible compensatory action was repeated.

Handgrip strength is a valid and reliable indicator of overall muscular strength and functional capacity: test–retest reliability of dynamometry is consistently good to excellent (typical ICCs ≥ 0.85 and often > 0.90 when standardized protocols are used), and TKK handgrip devices demonstrate high technical reliability and validity against calibrated weights (Bohannon, 2017; Mathiowetz et al., 1984). Low handgrip strength is prospectively associated with elevated risks of all-cause and cardiovascular mortality in large, diverse cohorts, including the Prospective Urban Rural Epidemiology (PURE) study and UK Biobank, underscoring its epidemiological and clinical relevance in adult populations(Celis-Morales et al., 2018; Leong et al., 2015).

20-meter Multi-Stage Fitness Test (20 m MFT)

The 20-meter multi-stage fitness test (20 m MFT) was administered to evaluate participants' cardiorespiratory fitness, following the standardized protocol described previously (Léger et al., 1988). Testing took place in a gymnasium under controlled conditions, with ambient temperature maintained at 22 - 25°C and relative humidity at 50 - 60%. All participants wore standard athletic footwear.

To reduce potential learning effects, a familiarization session was conducted prior to the formal test. During the assessment, participants were instructed to run back and forth between two lines set 20 meters apart, synchronized with pre-recorded audio signals. The interval between signals decreased progressively at each stage, requiring participants to increase their running speed accordingly. The test was terminated when a participant failed to reach the line on two consecutive occasions.

The primary outcome measure was the total distance covered during the shuttle run, which was subsequently converted into predicted maximal oxygen consumption (VO_2max) using the validated equation previously (Léger et al., 1988).

One-Repetition Maximum (1RM) Squat Test

The one-repetition maximum (1RM) squat test was performed in accordance with the safety guidelines of the American College of Sports Medicine (ACSM, 2022). Although participants were novice lifters, direct 1RM testing was selected over submaximal prediction equations to enhance measurement accuracy, with risks minimized through strict safety protocols (Thompson et al., 2013).

Prior to testing, participants completed a standardized warm-up consisting of 5 minutes of low-intensity cycling, dynamic lower-limb stretching, and 1 - 2 sets of light-load squats. The assessment took place in a power rack, with safety pins adjusted to an appropriate height. Two experienced spotters were present throughout all attempts to provide immediate assistance if necessary. Squat depth was standardized to parallel, defined as the crest of the iliac tubercle aligned with the knee joint. Depth was verified using two complementary methods: (a) a lightweight physical marker (box) that participants lightly touched at the bottom of each squat, and (b) goniometric confirmation of 90° knee flexion, a method shown to be reliable in resistance-training research.

The incremental loading protocol began with a weight that participants could lift comfortably for 3 - 5 repetitions. Load was then progressively increased in 2.5 - 5 kg increments, with 3 - 5 minutes of rest between trials. Attempts were terminated if the participant deviated from correct form (e.g., excessive trunk flexion, heel lift), showed barbell stagnation, or required spotter assistance. The highest load lifted with proper technique and full range of motion was recorded as the 1RM. To ensure consistency and inter-rater reliability, all assessors completed standardized training in movement standards and failure criteria prior to data collection.

Statistical procedures

Normality and homogeneity of variance were assessed using the Shapiro - Wilk and Levene's tests, respectively, and further verified by visual inspection of Q - Q plots and residual-versus-fitted plots derived from the linear mixed models (LMMs). Normality assumptions were evaluated on model residuals rather than raw scores. When minor deviations from normality were observed, LMMs were retained because they are robust to moderate violations of parametric assumptions. In cases where residuals showed meaningful heteroscedasticity, models were re-estimated using robust (sandwich) standard errors to ensure valid inference.

Descriptive statistics were presented as mean ± standard deviation, and the significance level for all tests was set at $p < 0.05$. LMMs were used as the primary analytical approach to examine group, time, and group × time interaction effects across all health-related physical parameters. Each model included a random intercept for participants to account for individual baseline variability. Restricted maximum likelihood (REML) estimation was applied, which provides unbiased variance estimates and appropriately handles missing data under the intention-to-treat principle. When significant main or interaction effects were detected, Bonferroni-adjusted post hoc comparisons were conducted.

To quantify the magnitude of between-group differences, Cohen's effect sizes (ES) and their 90% confidence intervals were calculated. ES values were interpreted as follows: 0.0 - 0.2 negligible, 0.2 - 0.5 small, 0.5 - 0.8 medium, and >0.8 large. All statistical analyses were performed using SPSS (version 29.0.0, IBM SPSS Statistics, Armonk, New York, USA).

Results

The Table 3 presents the descriptive baseline characteristics of the participants and the comparisons between groups. For male participants, baseline assessments included body weight, body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), resting heart rate (RHR), bilateral handgrip strength, one-repetition maximum (1RM) squat, 20-meter multistage fitness test (20 m MFT) distance, and maximal oxygen uptake (VO_2max). Standardized mean differences (SMDs) between groups were all below 0.50, indicating no substantial baseline imbalances. For the SSG vs. HIIT comparison, SMDs ranged from –0.36 (RHR) to 0.31 (VO_2max), reflecting small to moderate differences; all other comparisons were ≤0.20 (small). Between the SSG and control groups (CG), SMDs of –0.25 (BMI) and 0.34 (SBP) were small to moderate, while the remaining parameters showed negligible differences (SMD < 0.20). For HIIT vs. CG, only the SMD for RHR (–0.22) indicated a small to moderate difference, with all others below 0.20.

Among female participants, the same baseline indicators were assessed. All SMDs between groups remained below 0.50, confirming comparable baseline characteristics. For SSG vs. HIIT, the largest difference was observed in BMI (SMD = –0.27), classified as small to moderate, while all other parameters were <0.20. In the SSG vs. CG comparison, SBP (SMD = –0.33) and DBP (SMD = 0.31) showed small to moderate differences, with negligible differences for other variables (SMD < 0.20). For HIIT vs. CG, small to moderate differences were noted for DBP (SMD = –0.22) and SBP (SMD = 0.30), whereas all remaining indicators exhibited minimal variation (SMD < 0.20).

Pre-to-Post adaptations

The intra-group changes observed after 16 weeks of intervention are presented in Table 4. Significant improvements were found across most measures in both the SSG and HIIT groups, whereas the control group showed little or no meaningful change.

In the SSG group, body weight (MD = –5.24 kg; 95% CI: –5.97 to –4.51; p < .001), BMI (MD = –1.77; 95% CI: –2.02 to –1.52; p < .001), systolic blood pressure (MD = –5.90 mmHg; 95% CI: –6.44 to –5.36; p < .001), diastolic blood pressure (MD = –3.40 mmHg; 95% CI: –4.11 to –2.69; p < .001), and resting heart rate (MD = –5.47 bpm; 95% CI: –6.18 to –4.76; p < .001) all decreased significantly. Handgrip strength declined for both hands, with the left hand showing a mean decrease of –2.18 kg (95% CI: –2.41 to –1.96; p < .001) and the right hand a decrease of –3.32 kg (95% CI: –3.68 to –2.95; p < .001). Similarly, one-repetition maximum (1RM) squat performance decreased significantly (MD = –6.83 kg; 95% CI: –7.41 to –6.25; p < .001). In contrast, cardiorespiratory performance improved markedly, with 20-meter shuttle run distance increasing by 186.00 m (95% CI: 169.98 to 202.02; p < .001) and VO_2max rising by 6.99 ml/kg/min (95% CI: 6.23 to 7.76; p < .001).

The HIIT group also demonstrated significant improvements across nearly all indicators. Reductions were observed in body weight (MD = –5.94 kg; 95% CI: –6.67 to –5.22; p < .001), BMI (MD = –2.00; 95% CI: –2.24 to –1.75; p < .001), systolic blood pressure (MD = –6.27 mmHg; 95% CI: –6.80 to –5.73; p < .001), diastolic blood pressure (MD = –3.67 mmHg; 95% CI: –4.38 to –2.96; p < .001), and resting heart rate (MD = –5.93 bpm; 95% CI: –6.64 to –5.22; p < .001). Both left and right handgrip strength declined modestly (MD = –1.34 kg and –1.80 kg, respectively; p < .001), and 1RM squat performance decreased by –6.13 kg (95% CI: –6.71 to –5.55; p < .001). Endurance capacity, however, showed significant improvement, as evidenced by a 212.67 m increase in 20-meter shuttle run performance (95% CI: 196.65 to 228.69; p < .001) and na 8.20 ml/kg/min rise in VO_2max (95% CI: 7.43 to 8.96; p < .001).

The control group displayed no significant changes in most parameters, including body weight (MD = –0.59 kg; p = .153), BMI (MD = –0.24; p = .063), diastolic blood pressure (MD = –0.57 mmHg; p = .162), resting heart rate (MD = –0.63 bpm; p = .097), 20-meter shuttle run performance (MD = 6.67 m; p = .937), and VO_2max (MD = –0.09 ml/kg/min; p = 1.000). Nonetheless, small but statistically significant declines were detected in systolic blood pressure (MD = –0.60 mmHg; p = .023), left-hand grip strength (MD = –0.32 kg; p = .002), right-hand grip strength (MD = –0.36 kg; p = .049), and 1RM squat performance (MD = –0.80 kg; p = .003).

Between-group comparisons revealed several notable effects. After 16 weeks of intervention, BMI was significantly lower in the SSG group compared to the control group (MD = –1.953; 95% CI: –3.684 to –0.223; p = .021), whereas the difference between the HIIT and control groups was not significant (MD = –1.470; p = .123). No significant differences were observed between the SSG and HIIT groups for either BMI or body weight (all p > .05). For blood pressure, both SSG and HIIT groups showed significantly lower systolic values than the control group (SSG vs. CG: MD = –5.433 mmHg; p < .001; HIIT vs. CG: MD = –6.000 mmHg; p < .001). Diastolic pressure was significantly lower in the HIIT group compared to the control group (MD = –2.767 mmHg; p = .025), whereas the difference between SSG and CG did not reach statistical significance (p = .075). There were no significant differences in blood pressure between the two intervention groups.

Resting heart rate followed a similar pattern, with both SSG and HIIT groups showing significantly lower post-intervention values than the control group (SSG vs. CG: MD = –5.267 bpm; p < .001; HIIT vs. CG: MD = –4.733 bpm; p < .001), but no significant difference between SSG and HIIT (p = 1.000). In terms of muscular strength, both the SSG and HIIT groups achieved significantly higher 1RM squat values than the control group (SSG vs. CG: MD = 6.067 kg; p = .026; HIIT vs. CG: MD = 5.733 kg; p = .039). However, differences in left- and right-handgrip strength between the intervention and control groups were not significant (p > .05).

Table 3. Comparison of baseline characteristics of participants in different groups (mean ± standard deviation.

	Measure	Total (n = 90)	SSG (n = 30)	HIIT (n = 30)	CG (n = 30)	SMD (SSG –HIIT)	SMD (SSG –CG)	SMD (CG – HIIT)
Men (n = 45)	Weight (kg)	75.15 ± 9.71	74.93 ± 10.96	75.00 ± 10.73	75.52 ± 7.81	-0.01	-0.06	0.06
	BMI (kg/m²)	23.38 ± 2.75	22.98 ± 2.96	23.60 ± 3.48	23.57 ± 1.61	-0.19	-0.25	-0.01
	SBP (mmHg)	127.76±3.31	128.27 ± 3.58	127.73 ± 4.03	127.27 ± 2.22	0.14	0.34	-0.14
	DBP (mmHg)	83.82 ± 4.31	83.67 ± 5.45	83.87 ± 4.34	83.93 ± 3.15	-0.04	-0.06	0.02
	Resting HR (bpm)	71.67 ± 3.66	70.00 ± 4.09	72.40 ± 3.76	71.60 ± 3.48	-0.36	-0.16	-0.22
	Handgrip Left(kg)	40.87 ± 3.16	40.99 ± 2.10	41.05 ± 3.71	40.57 ± 3.63	-0.02	0.15	-0.13
	Handgrip Right (kg)	42.78 ± 3.08	42.47 ± 2.16	43.63 ± 4.12	42.98 ± 2.84	-0.37	-0.20	-0.19
	1RM (kg)	52.87 ± 7.05	52.67 ± 7.94	53.47 ± 7.59	52.47 ± 5.90	-0.10	0.03	-0.15
	20m MFT (m)	510.22 ± 130.15	524.00 ± 119.81	492.00 ± 116.08	514.67 ± 157.56	0.27	0.07	0.16
	VO_2max (ml/kg/min)	35.92 ± 5.14	36.55 ± 4.90	35.07 ± 4.55	36.14 ± 6.09	0.31	0.07	0.20
Women (n = 45)	Weight (kg)	64.4 ± 8.84	64.05 ± 9.28	65.30 ± 8.88	63.87 ± 8.89	-0.14	0.02	-0.16
	BMI (kg/m²)	23.08 ± 2.9	22.73 ± 3.02	23.53 ± 2.91	22.98 ± 2.93	-0.27	-0.08	-0.19
	SBP (mmHg)	129.4 ± 3.75	128.93 ± 3.94	129.07 ± 3.58	130.20 ± 3.86	-0.04	-0.33	0.30
	DBP (mmHg)	82.93 ± 3.51	83.53 ± 3.80	83.00 ± 2.54	82.27 ± 4.11	0.17	0.31	-0.22
	Resting HR (bpm)	73.89 ± 3.48	73.60 ± 3.92	74.20 ± 3.69	73.87 ± 2.97	-0.16	-0.08	-0.10
	Handgrip Left (kg)	30.87 ± 3.34	30.91 ± 4.31	30.80 ± 3.04	30.91 ± 2.66	0.03	0.00	0.04
	Handgrip Right (kg)	32.79 ± 3.48	32.84 ± 4.17	32.63 ± 3.29	32.91 ± 3.13	0.06	-0.02	0.09
	1RM (kg)	40.82 ± 4.34	40.80 ± 4.21	40.73 ± 4.11	40.93 ± 4.96	0.02	-0.03	0.04
	20m MFT (m)	374.22 ± 78.58	373.33 ± 44.51	377.33 ± 98.81	372.00 ± 87.44	-0.05	0.02	-0.06
	VO_2max(ml/kg/min)	30.4 ± 2.48	30.26 ± 2.24	30.45 ± 2.69	30.49 ± 2.65	-0.08	-0.09	0.01

SSG: small-sided games; HIIT: high-intensity interval training; CG: control group; BMI: body mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; 1RM: One-Repetition Maximum; 20m MFT: 20-meter multi-stage fitness test; SMD: Standardized Mean Difference. Thresholds for interpreting SMD: <0.10 (negligible), 0.20 (small), 0.50 (medium), and 0.80 (large).

Table 4. **Descriptive statistics (mean ± standard deviation) and inferential statistics for the within- and between-group comparisons for the overall participants.**

	Indicators and Groups	Pre	Mid	Post	Change scores with 95% CI	Between-group differences at Post (adjusted means)	ES (95%CI)
Body mass (kg)	SSG (n = 30)	69.49 ± 11.41	66.40 ± 11.03	64.25 ± 10.80*	-5.24 (-5.97, -4.51)	SSG vs HIIT: 0.040 (-6.623, 6.703)	0.004 (-0.502, 0.510)
	HIIT (n = 30)	70.15 ± 10.86	66.50 ± 10.36	64.21 ± 10.05*	-5.94 (-6.67, -5.22)	SSG vs CG: -4.858 (-11.521, 1.805)	-0.464 (-1.00,0.79)
	CG (n = 30)	69.69 ± 10.14	69.58 ± 10.29	69.11 ± 10.13	-0.59 (-1.31, 0.14)	HIIT vs CG: -4.898 (-11.561, 1.765)	-0.485 (1.020,0.022)
BMI (kg/m²)	SSG (n = 30)	22.86 ± 2.94	21.82 ± 2.86	21.09 ± 2.73*	-1.77 (-2.02, -1.52)	SSG vs HIIT: -0.483 (-2.214, 1.247)	-0.171(-0.678, 0.336)
	HIIT (n = 30)	23.57 ± 3.15	22.35 ± 3.04	21.57 ± 2.91*	-2.00 (-2.24, -1.75)	SSG vs CG:-1.953 (-3.684, -0.223)	-0.755 (-1.31,-0.20)
	CG (n = 30)	23.28 ± 2.34	23.22 ± 2.33	23.04 ± 2.30	-0.24 (-0.48, 0.01)	HIIT vs CG:-1.470 (-3.201, 0.261)	-0.561 (-1.102, -0.021)
SBP (mmHg)	SSG (n = 30)	128.60 ± 3.71	125.57 ± 3.96	122.70 ± 3.88*	-5.90 (-6.44, -5.36)	SSG vs HIIT: 0.567 (-1.661, 2.795)	0.158 (-0.350, 0.664)
	HIIT (n = 30)	128.40 ± 3.80	125.60 ± 3.58	122.13 ± 3.27*	-6.27 (-6.80, -5.73)	SSG vs CG:-5.433 (-7.661, -3.205)	-1.466 (-1.98, -0.96)
	CG (n = 30)	128.73 ± 3.43	128.67 ± 3.29	128.13 ± 3.53	-0.60 (-1.14, -0.06)	HIIT vs CG:-6.000 (-8.228, -3.772)	-1.764 (-2.253, -1.213)
DBP (mmHg)	SSG (n = 30)	83.60 ± 4.61	81.97 ± 4.48	80.20 ± 4.41*	-3.40 (-4.11, -2.69)	SSG vs HIIT: 0.433 (-2.065, 2.932)	0.112 (-0.395, 0.618)
	HIIT (n = 30)	83.43 ± 3.52	81.73 ± 3.33	79.77 ± 3.27*	-3.67 (-4.38, -2.96)	SSG vs CG:--2.333 (-4.832,0.165)	-0.562 (-1.04, -0.59)
	CG (n = 30)	83.10 ± 3.70	82.77 ± 3.94	82.53 ± 3.89	-0.57 (-1.28, 0.14)	HIIT vs CG:-2.767 (-5.265,-0.268)	0.77 (-1.274, -0.258)
Resting HR (bpm)	SSG (n = 30)	72.30 ± 4.04	69.87 ± 4.08	66.83 ± 3.76*	-5.47 (-6.18, -4.76)	SSG vs HIIT:-0.533 (-2.721, 1.654)	-0.156 (-0.663, 0.351)
	HIIT (n = 30)	73.30 ± 3.77	71.07 ± 3.70	67.37 ± 3.02*	-5.93 (-6.64, -5.22)	SSG vs CG:-5.267 (-7.454, -3.079)	-1.530 (-2.03, -1.02)
	CG (n = 30)	72.73 ± 3.38	72.07 ± 3.16	72.10 ± 3.10	-0.63 (-1.34, 0.08)	HIIT vs CG:-4.733 (-6.921,-2.546)	-1.546 (-2.041, -1.000)
Handgrip Left (kg)	SSG (n = 30)	35.95 ± 6.11	37.03 ± 6.36	38.13 ± 6.40*	-2.18 (-2.41, -1.96)	SSG vs HIIT:0.873 (-3.018, 4.764)	0.136 (-0.371, 0.642
	HIIT (n = 30)	35.92 ± 6.19	36.36 ± 6.47	37.26 ± 6.42*	-1.34 (-1.56, -1.11)	SSG vs CG:2.077 (-1.814, 5.968)	0.338 (-0.21, 0.87)
	CG (n = 30)	35.74 ± 5.82	35.64 ± 5.98	36.06 ± 5.88*	-0.32 (-0.55, -0.10)	HIIT vs CG:1.203 (-2.688, 5.094)	0.2 (-0.32, 0.72)
Handgrip Right (kg)	SSG (n = 30)	37.66 ± 5.89	39.32 ± 6.06	40.97 ± 6.37*	-3.32 (-3.68,-2.95)	SSG vs HIIT:-1.417 (-5.312, 2.478)	0.219 (-0.290, 0.726)
	HIIT (n = 30)	37.76 ± 6.37	38.47 ± 6.45	39.56 ± 6.57*	-1.80 (2.16,-1.43)	SSG vs CG:-2.077 (-5.972, 1.818)	0.432 (-0.68, 0.95)
	CG (n = 30)	37.94 ± 5.90	38.13 ± 5.95	38.31 ± 5.97*	-0.36 (-0.76,-0.00)	HIIT vs CG:-0.660 (-4.555, 3.235)	0.2 (-0.32, 0.74)
1RM (kg)	SSG (n = 30)	46.73 ± 8.69	50.33 ± 8.84	53.57 ± 9.20*	-6.83 (-7.41, -6.25)	SSG vs HIIT: 0.333 (-5.189, 5.856)	0.035 (-0.471, 0.541)
	HIIT (n = 30)	47.10 ± 8.83	50.73 ± 9.12	53.23 ± 9.65*	-6.13 (-6.71, -5.55)	SSG vs CG: 6.067 (0.544, 11.589)	0.694 (0.18,1.23)
	CG (n = 30)	46.70 ± 7.94	47.17 ± 8.06	47.50 ± 8.27*	-0.80 (-1.38, -0.22)	HIIT vs CG:5.733 (0.211, 11.256)	0.638 (0.115,1.227)
20 m MFT (m)	SSG (n = 30)	448.67 ± 117.29	536.00 ± 135.99	634.67 ± 133.80*	186.00 (169.98, 202.02)	SSG vs HIIT: -12.667 (-95.538, 70.205)	-0.099 (-0.605, 0.408)
	HIIT (n = 30)	434.67 ± 120.91	544.00 ± 123.11	647.33 ± 121.99*	212.67 (196.65, 228.69)	SSG vs CG: 184.667 (101.795, 267.538)	1.329 (0.80, 1.81)
	CG (n = 30)	443.33 ± 144.71	446.00 ± 143.57	450.00 ± 144.01	6.67 (-9.35, 22.69)	HIIT vs CG:197.333 (114.462, 280.205)	1.48 (0.97, 2.01)
VO_2max (ml/kg/min)	SSG (n = 30)	33.41 ± 4.93	36.54 ± 5.79	40.40 ± 5.82*	-6.99 (-7.76, -6.23)	SSG vs HIIT: -0.553 (-3.885, 2.778)	-0.098 (-0.596, 0.409)
	HIIT (n = 30)	32.76 ± 4.36	36.62 ± 5.10	40.95 ± 5.51*	-8.20 (-8.96, -7.43)	SSG vs CG: 6.993 (3.662, 10.325)	1.237 (0.72, 1.77)
	CG (n = 30)	33.32 ± 5.43	33.30 ± 5.56	33.41 ± 5.49	-0.09 (-0.85, 0.67)	HIIT vs CG:7.547 (4.215, 10.878)	1.37 (0.88, 1.92)

SSG: small-side games; HIIT: high-intensity interval training; CG: control group; BMI: body mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; 1RM: One – Repetition Maximum; 20-meter multi-stage fitness test (20 m MFT); VO_2max: maximal oxygen uptake; * significantly differences between the pre and the post ($p < 0.05$).

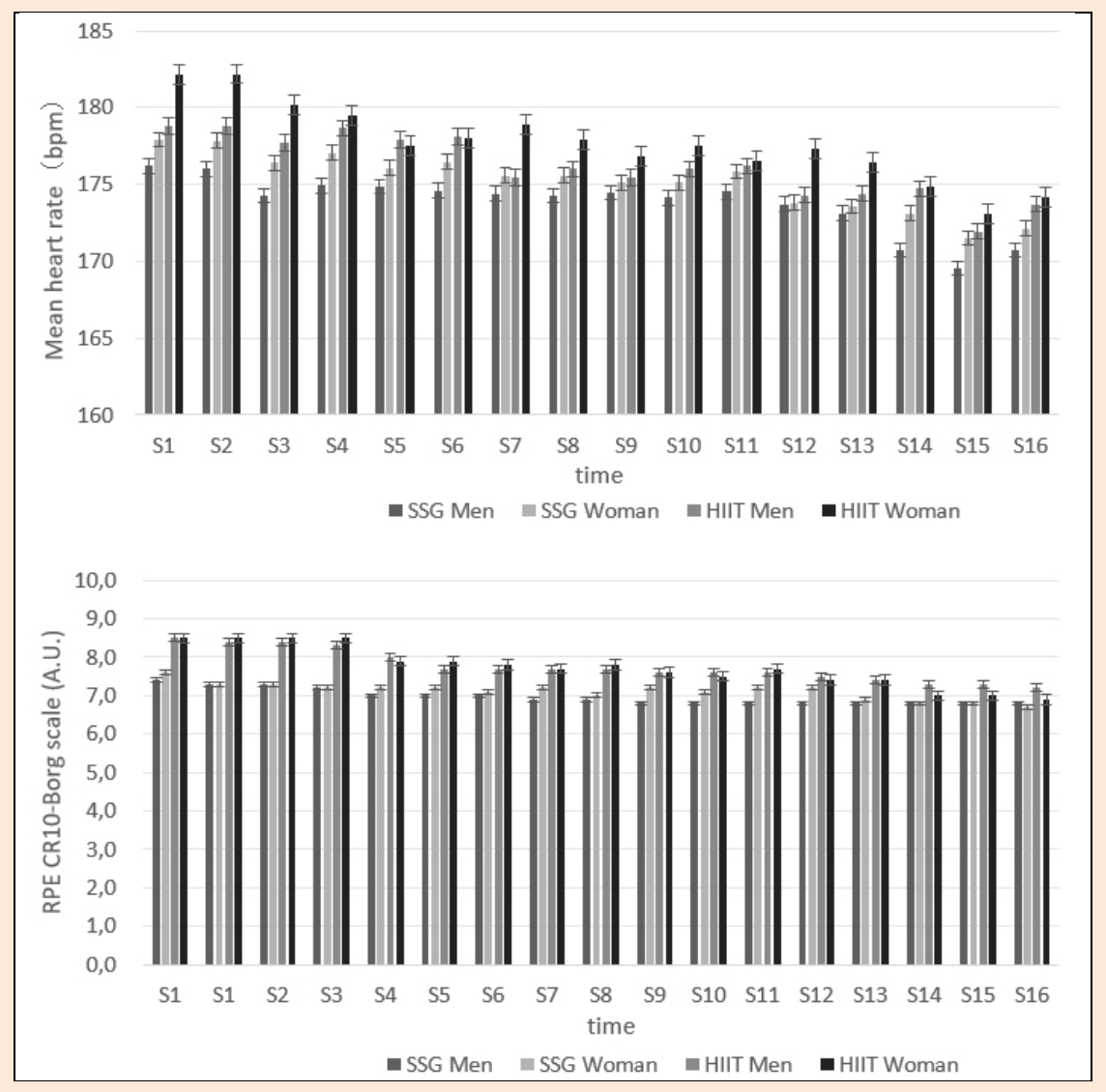

Figure 2. Descriptive statistics (mean and standard deviation) of mean heart rate and perceived exertion levels among volunteers in the SSG and HIIT groups throughout the experimental sessions.

Regarding aerobic fitness, there was no significant difference in 20-meter shuttle run performance between the SSG and HIIT groups (MD = –12.67 m; p = 1.000). Nevertheless, both training groups outperformed the control group substantially (SSG vs. CG: MD = 184.67 m; p < .001; HIIT vs. CG: MD = 197.33 m; p < .001). Similarly, no significant difference in VO_2max was found between SSG and HIIT (MD = –0.55 ml/kg/min; p = 1.000), but both groups demonstrated markedly higher VO_2max compared with the control group (SSG vs. CG: MD = 6.99 ml/kg/min; p < .001; HIIT vs. CG: MD = 7.55 ml/kg/min; p < .001).

Training load monitoring

Figure 2 illustrates the descriptive statistics for the average heart rate and perceived exertion (PRE) of participants in the SSG and HIIT groups throughout the intervention. At baseline, the mean PRE in the SSG group was 6.9 ± 0.2 for males and 7.1 ± 0.2 for females, while in the HIIT group it was 7.7 ± 0.3 for males and 7.7 ± 0.4 for females. Across the 16-week training period, the HIIT group consistently reported higher PRE values than the SSG group, and this difference remained stable across both genders and all time points. Within each group, females reported slightly higher perceived exertion levels than males.

Overall, irrespective of training group or gender, participants' perceived exertion gradually declined over the course of the intervention, demonstrating a typical pattern of physiological adaptation. This downward trend likely reflects improved tolerance to repetitive exercise loads and an increased perceptual threshold for exertion as participants became more conditioned.

Regarding heart rate responses, the average heart rate in the SSG group was 172.5 ± 2.5 bpm for males and 173.0 ± 2.4 bpm for females, while in the HIIT group it was 174.5 ± 2.6 bpm for males and 176.8 ± 3.0 bpm for females. The overall mean heart rate of the HIIT group was significantly higher than that of the SSG group, indicating a greater physiological load imposed by the HIIT intervention. Within-group comparisons showed that women generally exhibited slightly higher heart rates than men, suggesting greater cardiovascular responsiveness under

equivalent exercise conditions. Furthermore, both groups demonstrated a gradual decline in average heart rate over the training period, consistent with the phenomenon of training adaptation. This progressive reduction indicates that physiological responses to fixed-intensity exercise became more stable and efficient over time, likely reflecting enhanced cardiovascular adaptability and improved autonomic nervous system regulation.

Figure 3 illustrates the variations in exercise volume across the five measurement points (T0–T4) for each group. The control group (CG) maintained a stable exercise volume throughout the intervention, with mean values remaining close to baseline: T0 (443.2 ± 170.2 MET-min/week), T1 (447.9 ± 166.9 MET-min/week), T2 (455.9 ± 174.9 MET-min/week), T3 (467.2 ± 169.6 MET-min/week), and T4 (488.8 ± 170.5 MET-min/week). This stability effectively rules out the influence of spontaneous physical activity (i.e., unstructured exercise outside the intervention) on the improvements observed in physiological indicators such as body weight, blood pressure, and aerobic capacity, confirming that these changes were attributable to the experimental training protocols rather than external confounders.

In contrast, both the small-sided games group (SSG) and the high-intensity interval training group (HIIT) demonstrated substantial increases in exercise volume consistent with their prescribed training loads. For the SSG group, exercise volume rose progressively from T0 (435.3 ± 97.0 MET-min/week) to T4 (1145.3 ± 75.1 MET-min/week), with intermediate values of 1066.6 ± 101.3, 1096.5 ± 84.0, and 1109.7 ± 78.6 MET-min/week at T1, T2, and T3, respectively. A similar trend was observed in the HIIT group, where exercise volume increased from T0 (442.1 ± 85.3 MET-min/week) to T4 (1206.3 ± 184.7 MET-min/week), with intermediate values of 1116.4 ± 165.3, 1122.4 ± 185.6, and 1179.7 ± 184.3 MET-min/week

The consistent alignment between the increased exercise volume in the SSG and HIIT groups and their intervention parameters (training frequency, duration, and intensity) indicates that the physiological and fitness improvements observed—such as enhanced aerobic capacity and reduced blood pressure—were primarily attributable to the structured training interventions rather than additional unmonitored physical activity.

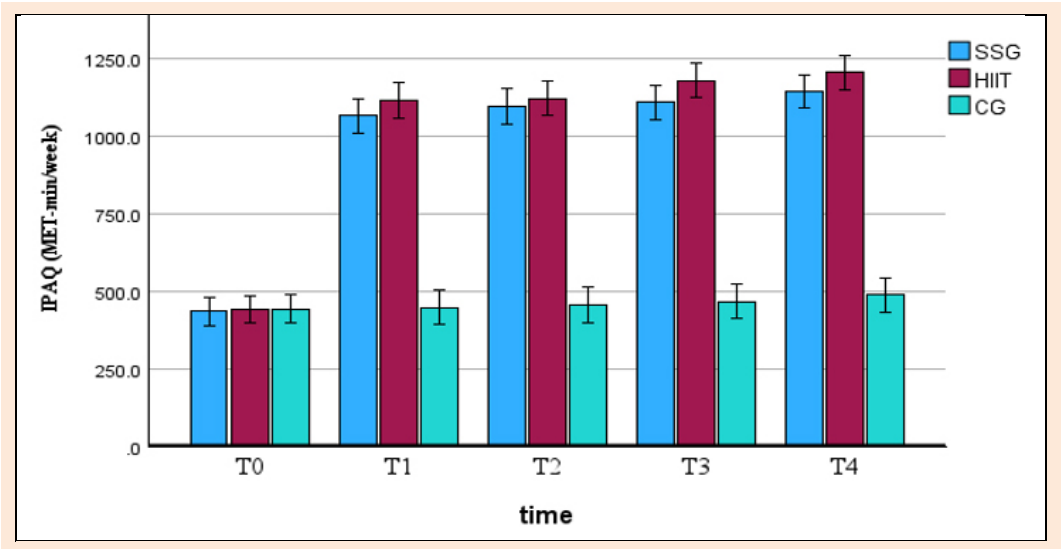

Figure 3. Dynamic changes in physical activity levels (IPAQ-SF) among three groups during the 16-week intervention.

Discussion

This study investigated the effects of SSG and HIIT on physiological and physical performance in sedentary young adults over a 16-week intervention. Relative to a control group (CG) with minimal changes, both modalities significantly improved key outcomes: physiological indicators (body weight, BMI, blood pressure, resting heart rate) and physical performance (hand grip strength, 20-meter multi-stage fitness test [MFT], 1RM lower limb strength). Particularly, SSG elicited greater benefits in hand grip strength, whereas HIIT more substantially enhanced aerobic capacity—collectively demonstrating the efficacy of active training for sedentary populations.

For body weight and BMI, both SSG and HIIT outperformed the control group. These findings align with the capacity of both modalities to increase total energy expenditure and stimulate fat oxidation—via enhanced lipid metabolism—while preserving lean mass (Jurišić et al., 2024; Soylu et al., 2021). Specifically, the high-intensity intermittent nature of HIIT induces considerable energy demand within short periods and elicits a pronounced excess post-exercise oxygen consumption (EPOC) effect, thereby enhancing caloric expenditure even after exercise cessation (Boutcher, 2011; Demirman et al., 2024). Research indicates that HIIT is more effective than traditional continuous cycling in reducing overall body fat and visceral adipose tissue (Maillard et al., 2018). A meta-analysis focusing on obese adolescents further corroborates that HIIT significantly improves body composition, leading to reductions in weight, BMI, body fat percentage, and waist circumference (all $p < 0.05$) (Zhu et al., 2021).

Similarly, SSG represents a composite training modality that integrates high-intensity intermittent aerobic exercise with sport-specific skills. The inherent alternation between high- and low-intensity phases during SSG signif-

icantly increases energy expenditure and stimulates fat oxidation (Sampson et al., 2021). One study reported that 12 weeks of SSG led to a 7 ± 7% reduction in total fat mass and a 6 ± 7% decrease in body fat percentage (Hornstrup et al., 2019). Moreover, the diverse movements embedded in SSG—such as sprinting, jumping, abrupt decelerations, directional changes, and passing—provide considerable mechanical load. This load effectively promotes muscle protein synthesis, which aids in fat loss and subsequent BMI reduction (Hornstrup et al., 2019; Jurišić et al., 2024; Xu et al., 2024). A systematic review affirms that recreational team sports can significantly lower BMI in overweight/obese individuals, with reductions ranging from -2.3% to -5.1% (Wang et al., 2024), a finding consistent with other studies demonstrating the efficacy of SSG in reducing weight and BMI (Sampson et al., 2021).

Furthermore, a consistent reduction in resting heart rate was observed following both training interventions. a finding consistent with previous studies. For example, a 6-week full-body HIIT program significantly reduced resting heart rate from 73.94 ± 13.2 bpm to 66.1 ± 10.8 bpm ($p = 0.046$) (Songsorn et al., 2022). A meta-analysis further confirmed that HIIT significantly reduces resting heart rate (-2.17 bpm, $p = 0.0002$) compared to control conditions, underscoring its role in improving cardiac autonomic regulation and reducing cardiovascular risk (de Souza Mesquita et al., 2022).This reduction is clinically meaningful as it typically reflects enhanced vagal tone and increased cardiac stroke volume, indicating improved cardiovascular efficiency whereby the heart meets metabolic demands with fewer contractions per minute (Ramos et al., 2015).

Specifically, HIIT promotes left ventricular remodeling (e.g., increased end-diastolic volume) and improves ejection fraction, thereby enhancing pumping efficiency (Baggish, 2016). Concurrently, it modulates autonomic balance by increasing parasympathetic (vagal) activity and reducing sympathetic dominance at rest (Boutcher, 2011; Hautala et al., 2009). Moreover, the efficacy of HIIT in lowering resting heart rate is well-established across diverse populations, including healthy individuals and those at high cardiovascular risk (de Souza Mesquita et al., 2022; Weston et al., 2014).

SSGs involve dynamic tactical interactions and variable intensity patterns, whose inherent high-intensity intermittent nature is equally capable of inducing beneficial cardiovascular physiological adaptations. For instance, a study showed that after 12 weeks of handball training reduced resting heart rate by 16% (Póvoas et al., 2018). This effect has also been found in similar team sports. For instance, in a study comparing small-sided football and basketball, resting heart rates decreased by 5.3% and 5.5% respectively (Qi et al., 2025). Thus, despite differences in exercise structure—with HIIT providing precisely controlled high-intensity stimuli and SSG integrating social, cognitive, and intermittent physical elements—both modalities effectively promote positive structural and functional cardiac adaptations, resulting in sustained resting heart rate reduction and overall cardiovascular health improvement (Batacan et al., 2017).

Both SSG and HIIT effectively improved physiological markers in previously sedentary individuals, with blood pressure regulation representing a key area of benefit. In the SSG group, systolic and diastolic blood pressure decreased by 4.7% and 4.1% respectively in male participants, and by 4.5% and 4.0% in female participants. These findings align with previous research demonstrating that 12 weeks of recreational handball training reduced diastolic blood pressure by 4 mmHg in adult men (Póvoas et al., 2018). A comparative study on soccer and basketball revealed that both sports significantly reduce systolic blood pressure by 2.6%, while diastolic blood pressure decreases by 4.7% and 5.4% respectively (Xu et al., 2024). A systematic review further corroborates that team-based interventions can reduce systolic blood pressure by 3.9–8.3% and diastolic pressure by an average of 7.3% (Wang et al., 2024).underscoring the broad applicability of team sports in improving cardiovascular health. The blood pressure-lowering effects of team sports like SSG can be attributed to their integration of dynamic movements—such as acceleration, directional changes, and jumping—which enhance vascular dilation through endothelial nitric oxide (NO) release, reduce arterial stiffness, and decrease peripheral vascular resistance (Barone Gibbs et al., 2012).

Similarly, HIIT elicited substantial blood pressure improvements, with reductions of 5.0% in systolic and 4.5% in diastolic pressure among males, and 4.8% and 4.3% among females. This is consistent with a systematic review concluding that HIIT significantly enhances cardiometabolic parameters, particularly those related to metabolic syndrome, with average reductions of 6 mmHg in systolic and 3.68 mmHg in diastolic blood pressure (Poon et al., 2024). Another review reported that HIIT reduced systolic and diastolic blood pressure by averages of 4.57 mmHg and 2.94 mmHg, respectively, in overweight/obese individuals (Batacan et al., 2017). Although HIIT involves high-intensity efforts, its cardiovascular benefits arise not from prolonged duration but from potent physiological adaptations triggered by brief, intense stimuli (Ramos et al., 2015). Mechanisms include improved autonomic nervous system regulation, enhanced endothelium-dependent vasodilation, and modulation of the renin-angiotensin system, collectively contributing to effective blood pressure control (Opazo-Díaz et al., 2024).

This study demonstrates that while both SSG and HIIT effectively improve overall physical fitness, SSG offers a distinct advantage in enhancing upper body strength (Delextrat and Martinez, 2014; Dello Iacono et al., 2016; Granados et al., 2007; Johnston et al., 2013). Specifically, the SSG group exhibited significantly greater improvements in grip strength compared to the HIIT group. This phenomenon may be attributed to the nature of handball, which involves frequent rapid and explosive upper limb movements such as passing, shooting, and blocking. These technical actions require players to repeatedly perform gripping, forceful exertion, and fine motor control under dynamic conditions, thereby providing high-intensity, multimodal resistance to the forearm flexor muscles. Such direct mechanical loading not only promotes muscular hypertrophy but also enhances neural recruitment efficiency and motor unit synchronization, ultimately leading to significant improvements in maximal grip strength and rate of force development (RFD) (Gorostiaga et al., 2006;

Johnston et al., 2013; Pereira et al., 2023). For instance, a study shows that a 36-week competitive handball training program increased the athletes' grip strength by 12%.(Pereira et al., 2023).Another study reported that the small-sided games group exhibited a greater improvement in handball-specific throwing ability (6.43% increase) compared to the high-intensity interval training group (3.77% increase), highlighting the dual benefits of small-sided games for both upper limb strength and skill development (Vukadinović Jurišić et al., 2021). A study measured changes in upper and lower limb strength following short-term high-intensity interval running training. The results indicated that while lower limb strength showed significant improvement, upper limb strength did not show statistically significant enhancement (Astorino et al., 2012). SSG exposes participants to high movement variability, requiring frequent transitions between accelerations, decelerations, reaching actions, body contacts, and stabilizing movements during defensive and offensive interactions. Such variability engages the upper limbs through repeated spontaneous actions as pushing, bracing, reaching, balance correction, and incidental contact, which create diverse loading patterns not present in linear exercise modalities.

Both SSG and HIIT have been established as effective modalities for enhancing aerobic capacity (Dello Iacono et al., 2015; 2016; Kunz et al., 2019; Ouertatani et al., 2022), a conclusion further supported by the findings of this study. A meta-analysis indicates that both HIIT and SSG elicit medium to large effect sizes in improving key endurance-related metrics, including peak oxygen uptake (VO_2peak), maximal running speed, sub-lactate threshold running performance, and running economy (Kunz et al., 2019).Another study specifically notes significant enhancements in the maximal aerobic speed (MAS) of young elite football players following both types of training (Ouertatani et al., 2022). These consistent improvements in cardiorespiratory function likely originate from the shared characteristic of intermittent high-intensity exertion.

Specifically, HIIT enhances aerobic capacity through structured high-intensity running intervals that activate crucial enzymes involved in skeletal muscle aerobic metabolism, promote mitochondrial biogenesis and function, and elicit sustained high heart rates during sessions. For instance, a six-week HIIT program was shown to improve cardiorespiratory function by 11.38% in active university students aged 20 - 25 (Manescu, 2025). Moreover, systematic reviews confirm that HIIT effectively improves cardiopulmonary fitness in patients with type 2 diabetes, primarily through mechanisms such as enhanced muscular oxidative capacity, increased mitochondrial density, and improved efficiency of aerobic metabolism (Lazić et al., 2024; Martland et al., 2020).

Similarly, SSG generates substantial aerobic metabolic demand through repeated sprints, multidirectional changes, and rapid transitions between offensive and defensive actions inherent to game-based activities. A study involving adult men reported an 80% improvement in Yo-Yo Intermittent Endurance Test Level 2 (YYIE2) performance and a 14% increase in VO_2max after 12 weeks of recreational handball training (Póvoas et al., 2018). Another study on post-menopausal women who did not receive systematic training showed that 16 weeks of recreational handball training significantly improved the aerobic capacity of this population, specifically showing an increase of 70% in the Yo-Yo intermittent endurance test level 1 (YYIE1) score and a 6.6% increase in peak oxygen uptake (VO_2peak).Another study focusing on untrained postmenopausal women found that 16 weeks of recreational handball led to a 70% improvement in Yo-Yo Intermittent Endurance Test Level 1 (YYIE1) performance and a 6.6% increase in VO_2peak(Pereira et al., 2020).

The absence of significant between-group differences in most physiological outcomes suggests that distinct training modalities—structured HIIT and game-based SSG—may elicit comparable systemic adaptations when overall intensity and workload are broadly matched. This pattern is consistent with comparative trials showing that SSG and HIIT produce similar improvements in aerobic fitness, repeated-sprint performance, and other performance markers in youth and team-sport athletes (Jurišić et al., 2021). More broadly, network meta-analytic and intervention studies indicate that different exercise modalities (e.g., continuous endurance, interval, and resistance training) can yield similar cardiometabolic benefits when energy expenditure and intensity are appropriately prescribed, supporting the notion of functional equivalence in exercise physiology (Batrakoulis et al., 2022). Within this framework, HIIT and SSG may represent alternative "training pathways" that converge on comparable adaptations in cardiorespiratory fitness and cardiometabolic health, even though their movement patterns, perceptual demands, and contextual features differ.

In the present study, the HIIT group exhibited slightly greater improvement in the 20-meter multi-stage fitness test (MFT) than the SSG group. This aligns with previous findings where HIIT produced a 28.40% improvement in Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1), significantly outperforming an aerobic exercise control group (17.63% improvement) with a larger effect size (Vukadinović Jurišić et al., 2021).This discrepancy may be attributed to the more variable intensity inherent in SSG—owing to its reliance on dynamic interpersonal interactions—which can lead to less consistent individual physiological stimuli. In contrast, HIIT employs a standardized work-to-rest structure that may more precisely target and stimulate physiological mechanisms central to aerobic adaptation (Akaras et al., 2024; Stankovic et al., 2023). Therefore, HIIT may hold a slight advantage for maximizing gains in aerobic endurance.

In this study, the lower limb strength of both the SSG group and the HIIT group showed significant improvement. Specifically, the 1RM leg extension strength of male and female participants in the SSG group increased by 14.3% and 15.6% respectively, while the HIIT group also achieved increases of 12.3% and 13.6%. The superior improvement in strength following SSG is likely attributable to the sport-specific explosive movements inherent to handball-based training, such as jump shots, rapid changes of direction, and accelerations. These high-intensity ac-

tions provide substantial mechanical loading and neuromuscular challenges that effectively stimulate the development of lower limb power and strength (Iacono et al., 2015; Pereira et al., 2021).These findings align with previous research conducted on female handball players, which similarly reported significant increases in 1RM leg extension strength following sport-specific training (Osborne et al., 2025).Furthermore, the greater improvements in countermovement jump performance (both CMJ and CMJ with arm swing) observed in the SSG group compared to the HIIT group (Dello Iacono et al., 2015),further support the advantage of game-based training for enhancing explosive power.

Although HIIT mainly takes the form of running, its training structure can still promote the development of lower limb strength through various physiological mechanisms. Existing studies have shown that a 6-week HIIT intervention can increase the vertical jumping ability of male leisure participants in universities by 9.11% (Manescu, 2025).A systematic review further indicates that HIIT can effectively enhance explosive power and strength levels by promoting adaptive changes in fast muscle fibers, optimizing neuromuscular coordination and efficiency(Hung et al., 2025).Additionally, long-term HIIT programs have been shown to enhance muscle endurance in previously sedentary young women (Martland et al., 2020).In conclusion, both SSG and HIIT represent effective strategies for enhancing lower limb strength and reducing the risk of falls and fractures in sedentary populations (Fristrup et al., 2020).

There are certain limitations to this study. First, the study subject group was very limited, consisting mainly of young, healthy college students with fairly similar socioeconomic and educational backgrounds. Second, this study lacked long-term follow-up assessments. While the 16-week intervention provided valuable insights into physiological and performance adaptations in the short and medium term, they did not reflect whether these improvements could be sustained over a longer period. Therefore, future research should focus on expanding the scope of participants, including older adults who are sedentary and individuals with a higher risk of metabolic disorders (such as those with prediabetes, overweight or obesity). Additionally, future research should include longer follow-up periods - ranging from 6 months to several years - to assess long-term health outcomes, including the prevention or delay of the occurrence of chronic diseases (such as type 2 diabetes, hypertension, and cardiovascular diseases). These efforts will enhance the translational value of research results and support the development of sustainable, evidence-based exercise recommendations for a diverse population of different ages. Finally, handgrip strength was included as a global indicator of muscle function but was not directly targeted by the lower-limb–dominant training stimuli, which may partly explain the absence of improvement and the small, likely non-meaningful decreases observed in the intervention groups.

Although both male and female participants were included in each intervention arm, the present study was not designed to formally evaluate sex-by-intervention interaction effects. The overall pattern of results did not suggest obvious sex-specific divergence in the direction or magnitude of training adaptations across aerobic, cardiometabolic, or neuromuscular outcomes. Because biological sex can influence factors such as muscle fiber composition, hormonal milieu, and recovery kinetics, future studies with larger sex-stratified samples or factorial designs explicitly designed to detect interaction effects are warranted to determine whether subtle sex-based differences in responsiveness to HIIT or SSG exist. A further limitation is that general physical activity outside the intervention was assessed using the self-reported IPAQ-SF, which is subject to recall bias and tends to overestimate absolute activity levels. Although the instrument shows acceptable reliability and validity, its self-report nature may introduce measurement noise that could attenuate the precision of activity-related covariates.

Because both HIIT and SSG were delivered in a field-based setting rather than a controlled laboratory environment, the intervention possessed high ecological validity. Conducting training sessions on an outdoor track and in game-based contexts enhanced the real-world translational of the study, allowing the training responses to reflect the practical conditions under which recreational exercise is typically performed. This design choice strengthens the applicability of the findings to community and public-health settings where structured laboratory-based HIIT interventions may be less feasible.

Conclusion

This study compared the effects of SSG, HIIT, and a non-training control condition on physical health and fitness in sedentary, previously untrained young adults. Both SSG and HIIT produced meaningful improvements in body mass, BMI, blood pressure, and resting heart rate, as well as in physical performance outcomes such as handgrip strength, lower-limb strength, and aerobic capacity. Although the magnitude of change varied across outcomes, some modality-specific tendencies emerged. SSG appeared to confer comparatively greater benefits for upper-limb strength, potentially reflecting the diverse movement patterns inherent in game-based activity. In contrast, HIIT elicited larger improvements in aerobic capacity, consistent with its structured, high-intensity metabolic demands. Individuals seeking a more engaging, skill-oriented form of activity may prefer SSG, whereas those aiming for efficient improvements in cardiorespiratory fitness may find HIIT more suitable. Regardless of modality, gradual progression and appropriate supervision are recommended to support safe participation. Overall, the parallel benefits of SSG and HIIT suggest that physiological health improvements can be achieved through both structured exertion and socially embedded play, maybe highlighting the importance of inclusive exercise prescriptions capable of supporting broad population engagement.

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The author reports no actual or potential conflicts of interest. The datasets generated and analyzed in this study are not publicly available, but are available from the corresponding author who organized the study upon

reasonable request. All experimental procedures were conducted in compliance with the relevant legal and ethical standards of the country where the study was performed.

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Key points

- Both small-sided games (SSG) and high-intensity interval training (HIIT) significantly improved weight, BMI, blood pressure, resting heart rate, aerobic capacity, and lower-limb strength compared with the control group.
- SSG and HIIT produced similar overall health and fitness benefits, with no significant differences between them across most indicators.
- SSG showed stronger support for upper-limb strength, while HIIT provided slightly superior improvements in aerobic performance.

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