©Journal of Sports Science and Medicine (2026) **25**, 138-148
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2026.138

Research article

Unveiling Optimal Order of Power-Based Resistance and Short Sprint Interval Training in Maximizing Lower-Extremity Physical Fitness Attributes of Judo Athletes

Yongbing Chen [1], Chunlei Li [2]✉, Minghao Peng [2] and Jixin Shan [3]
[1] Department of Public Basic Course Teaching, Dianxi University of Applied Sciences, Dali, Yunnan, China; [2] School of Wushu, Chengdu Institute of Physical Education, Chengdu, Sichuan, China; [3] Affiliated Sport Hospital, Chengdu Institute of Physical Education, Chengdu, Sichuan, China

Abstract

The purpose of this study was to examine the effects of a 6-week combined power-based resistance training (RT) and short sprint interval training (SSIT), performed in different sequences (SSIT+RT or RT+SSIT), on the lower-body physical fitness of male Judo athletes. Twenty-four young male athletes volunteered for this study and were randomly assigned to one of three groups: SSIT+RT, RT+SSIT, or an active control (CON) group, with eight athletes in each group. The training groups participated in a 6-week intervention, training three times per week during the preparatory phase of annual training cycle. Following the intervention, both the SSIT+RT and RT+SSIT groups showed significant improvements ($p = 0.001$) in several performance measures including vertical jump (effect size [ES] = 1.58 and 0.85), 20-m linear sprint (ES = -1.22 and -0.53), Agility T-test (ES = -1.12 and -0.46), maximal strength (ES = 0.15 and 0.21), Specific Judo Fitness Test (SJFT; ES = -0.91 and -0.90), peak power (ES = 1.74 and 1.18), mean power (ES = 0.98 and 1.11), and cardiorespiratory fitness (ES = 1.17 and 1.03). In contrast, the CON group did not exhibit any significant changes post-training. Moreover, the SSIT+RT group demonstrated significantly greater improvements compared to the RT+SSIT group in vertical jump (ES = 0.62, $p = 0.024$), 20-m linear sprint (ES = -0.46, $p = 0.031$), Agility T-test (ES = -0.34, $p = 0.016$), and peak power output (ES = 0.79, $p = 0.009$). Conversely, the RT+SSIT group showed more pronounced strength gains than the SSIT+RT group (ES = 0.14, $p = 0.007$). In conclusion, it is recommended that incorporating SSIT at the beginning of a training session is more effective for improving jumping ability, sprinting speed, change of direction, and peak power output. Conversely, if the primary goal is to enhance muscular strength, it is advisable to prioritize RT at the start of the session.

Key words: Strength training, anaerobic power, combat sport, aerobic capacity.

Introduction

Judo is an intermittent and high-intensity combat sport that typically lasts for a minimum of 4 minutes (Miarka et al., 2012). It is characterized by bursts of high-intensity activity lasting between 15 to 30 seconds, interspersed with brief pauses of 5 to 10 seconds (Hernández-García et al., 2009). In a standard Judo tournament, victorious competitors often engage in 5 to 7 matches within a single day, with rest intervals ranging from 1 to 15 minutes between bouts, necessitating excellent physical conditioning (Miarka et al., 2012). The performance in Judo is significantly influenced by various physical components, including muscular strength and power, as well as both anaerobic and aerobic endurance (da Silva et al., 2022). From a metabolic perspective, Judo predominantly relies on the aerobic system (50 - 81%), followed by the ATP-PCr (12 - 40%) and glycolytic (6 - 10%) systems (Franchini et al., 2013; 2020). Despite the substantial aerobic contribution, success in Judo is primarily determined by the effectiveness of throwing techniques, which demand a high energy output over very short durations, a function primarily supported by the ATP-PCr system (Franchini et al., 2013). Consequently, it is recommended that training programs for Judo athletes focus on enhancing both aerobic and anaerobic capacities, along with improving muscular strength and power, as these elements are vital for executing the brief, high-effort actions that are essential for success in Judo (da Silva et al., 2022).

Numerous training strategies and techniques are employed to achieve the desired physical and metabolic conditioning for Judo athletes (da Silva et al., 2022; Hernández-García et al., 2009). Resistance training (RT) is acknowledged as an effective approach for improving strength and power performance in these athletes (Saraiva et al., 2014), whereas aerobic training (AT) is advantageous for enhancing aerobic metabolic pathways (Bonato et al., 2015; Franchini et al., 2016). However, the limited availability of training time in the current sports landscape creates difficulties, as it is often challenging to schedule separate sessions for RT and AT. To overcome this obstacle, professionals in strength and conditioning are investigating strategies to increase training efficiency without sacrificing quality (Gao and Yu, 2023). As a result, numerous athletes have begun to integrate both RT and AT within the same training session to improve their overall physical fitness and optimize both aerobic and anaerobic metabolic conditioning as well as physical fitness attributes (Da Silva et al., 2020; Pito et al., 2022). This training approach is referred to as the combined training method, which allows athletes to improve both the efficiency and effectiveness of their training programs when compared to RT or AT conducted separately (Brito et al., 2019). In fact, studies suggest that combined training approach may provide greater advantages than either RT or AT alone (Cadore et al., 2012; Petré et al., 2018; Lee et al., 2020); however, the sequence of these combinations may potentially influence the extent of adaptations in both muscular strength and power, as well

Received: 15 October 2024 / Accepted: 01 December 2025 / Published (online): 01 March 2026

as in aerobic performance (Terzis et al., 2016; Vorup et al., 2016). Indeed, beginning a training session with RT could serve as an advantageous approach to augment muscular strength and power, while starting with AT is more suitable for facilitating substantial improvements in aerobic performance (Terzis et al., 2016; Vorup et al., 2016); however, conducting AT after RT could induce negative effects on muscular power gains (Lee et al., 2020).

To effectively reduce the negative effects of combined training, it is advisable to alter the sequence and type of exercises performed during training intervention (Fyfe et al., 2016; Petré et al., 2018; Lee et al., 2020). Implementing intervals of several hours (specifically, 3 to 8 hours) between RT and AT sessions within the same day can help alleviate negative effects on physical performance (Lee et al., 2020). An alternative approach to mitigate these effects could involve adopting a training regimen characterized by power-based RT or an all-out effort during AT (Petré et al., 2018; Laursen and Buchheit, 2019).

In light of the high-intensity and intermittent nature of Judo athletes, it is important to recognize that short sprint interval training (SSIT), lasting less than 10 seconds, is more advantageous compared to other types of AT, such as continuous AT or high-intensity interval training (HIIT) (Franchini et al., 2016; Boullosa et al., 2022). Moreover, employing a power-based approach in RT may represent an effective method for fostering adaptive responses in these athletes, as it not only alleviates interference effects but also maximizes performance adaptations (Huang et al., 2023). Consequently, integrating running-based SSIT under all-out conditions, as opposed to continuous running or alternative forms of AT such as cycling, may alleviate the adverse effects on resistance exercise outcomes noted in prior studies (Buchheit and Laursen, 2013; Laursen and Buchheit, 2019). Moreover, to the authors' knowledge, there has been no investigation into the combination of SSIT and RT regarding physiological and physical performance adaptations in athletes, particularly within the realm of Judo.

Apart from the type of exercise employed during combined training (i.e., continues AT, cycling or HIIT, or RT with maximal or sub-maximal intensity), monitoring individual responses to training is of utmost importance when integrating a training program (Robinson et al., 2024). Previous studies that explored various forms and sequences of combined training primarily focused on the average results of the groups (Da Silva et al., 2020; Pito et al., 2022; Gao and Yu, 2023), often neglecting the individual responses to training. Conversely, it is critical to recognize the variability in adaptive responses among individuals when recommending a training program. It is essential to evaluate individual responses to training to enhance the effectiveness of training programs. However, there is a notable deficiency in research focused on this area, particularly concerning the inter-individual responses to the combination of SSIT and power-based RT after a 6-week preparatory phase. Additionally, uncertainty persists regarding the efficacy of combining SSIT and RT in improving the physical and physiological performance of Judo athletes, as well as the optimal sequencing of these training modalities for performance adaptations. Addressing the existing gaps in knowledge is crucial for advancing the understanding of how the integration of SSIT and RT can influence physical fitness and physiological adaptations in Judo athletes. This study specifically aims to evaluate the effects of a 6-week intervention, incorporating SSIT and RT in varying sequences (i.e., SSIT+RT or RT+SSIT), on the performance and adaptive responses of male Judo athletes.

We hypothesized that the combination of SSIT and RT is effective in fostering adaptations in physical performance; however, the order of implementation of SSIT and RT may significantly influence the magnitude of the adaptive responses in performance testing.

Methods

Sample size estimation and randomization

The appropriate sample size for this research was determined using G*Power software (Version 3.1.9.2, University of Kiel, Germany). The calculations incorporated an effect size of 0.8, a power of 0.8, and a significance level of 0.05, which were derived from a prior study by Franchini et al. (2016) that examined the effects of interval training on the physical performance adaptations of male Judo athletes. Consequently, a total of 8 subjects were allocated to each group, corresponding to the 8 weight classes. In accordance with the classification for the World Championship, three athletes from each weight category (60 kg or less, 66 kg or less, 73 kg or less, 81 kg or less, 90 kg or less, 100 kg or less, over 100 kg, and the open weight division) volunteered to take part in the study. The athletes were randomly assigned to one of three groups in a 1:1:1 ratio using a computer-generated random number. The process of randomization was executed with R software (version 2.14, Foundation for Statistical Computing) and remained unpredictable for both the authors and the participants.

Participants

The investigation engaged twenty-four young male Judo athletes from a regional academy, all of whom had prior participation in national events. The athletes were divided into three groups: a) SSIT+RT (n = 8, age = 22.6 ± 2.5 y, height = 175.3 ± 8.1 cm, weight = 74.8 ± 18.5 kg, training age = 8.5 ± 1.1 y, experience in RT and AT = 4.6 ± 1.2 y, b) RT+SSIT (n = 8; age = 22.3 ± 2.1 y, height = 177.6 ± 7.4 cm, weight = 78.5 ± 19.1 kg, training age = 8.9 ± 1.3 y, experience in RT and AT = 4.8 ± 1.5 y), and c) an active control group (CON, n = 8, age = 22.1 ± 2.9 y, height = 179.3 ± 7.4 cm, weight = 80.7 ± 19.9 kg, training age = 9.1 ± 1.6 y, experience in RT and AT = 5.1 ± 1.3 y). The athletes had prior experience with RT and various forms of AT, including continuous running and sprint interval training; however, they had not engaged in these activities for at least three months before participating in the study. Eligibility for the study was determined by specific inclusion and exclusion criteria, which included: a) no prior musculoskeletal issues that would hinder participation in the training program (Gharaat et al., 2025), b) no intake of dietary supplements within the last six months or during the study, and c) a background of over seven years in Judo training and competition, with at least four years of uninterrupted training before the study commenced. Participants were thoroughly briefed on the study's aims and potential risks, and they provided written informed consent, which received approval from the University's Ethics Committee, in line with the principles of the Declaration of Helsinki.

Study procedure

A randomized-controlled study was conducted involving Judo athletes who participated in a 9-week intervention structured into distinct phases: a 1-week familiarization, a 1-week pre-test, a 6-week training intervention, and a 1-week post-test. During the initial week, specifically on Monday, participants were brought into the laboratory to familiarize themselves with the study's objectives, testing procedures, and training protocols. This session provided participants with the opportunity to understand the test procedures and the testing environment. They experienced a single exposure to the test setup, accompanied by a comprehensive explanation of the protocol and expectations, without engaging in repeated trials or concentrating on stabilizing their performance. Additionally, participants' height was measured using a stadiometer (± 0.1, Seca, Germany), and their body mass was recorded with a digital scale (± 0.5, Tanita, Japan). Following the week 1, participants were involved in three testing sessions, each separated by 48 hours (i.e., Week 2). The testing included a countermovement vertical jump (CMVJ), a 20-m sprint, and an agility T-test on Day 1; the Specific Judo Fitness Test (SJFT) and lower-body maximal strength measured via leg press on Day 2; and Wingate anaerobic power along with an incremental exercise test on Day 3, respectively. To control for circadian rhythm effects on short-duration exercise performance, all assessments were scheduled for the afternoon at the same time (4 PM) before and after the training intervention. To ensure consistency in the performance evaluations, participants were instructed to wear identical footwear and clothes for both the pre-test and post-test assessments. Each testing session began with a standardized general warm-up, comprising 10 minutes of running and an additional 10 minutes dedicated to stretching and ballistic movements. This was followed by a specific warm-up tailored to the performance tests. All evaluations were conducted in the laboratory under temperature conditions of 27 to 28º and relative humidity levels ranging from 45 to 50%.

Countermovement vertical jump

Following the completion of five specific warm-up jumps, the maximal vertical jump height was assessed using a Vertec device (Power System, Knoxville, Tennessee), which provides measurements with an accuracy of one cm. To prepare for the measurement, participants positioned themselves directly beneath the Vertec, ensuring their feet were together and their heels remained on the ground. Following the stand and reach assessment, the participants flexed their ankles, knees, and hips to initiate a downward motion to a depth of their choosing (i.e., parallel to the ground), subsequently, extended their ankles, knees, and hips to achieve maximum vertical height. The procedure commenced with the participants in an upright position and the participants were instructed to contact the vanes on the Vertec when they reached to the peak jump height. During the CMVJ testing, participants were prohibited from swing their hands, and the dominant hand was required to be elevated to ensure that hand movement did not influence the results. The difference between the highest vane touched during the jump and the participant's standing reach was calculated, and the mean scores from three trials (Claudino et al., 2017), with a 30-second rest interval, was recorded for further analysis (Nuzzo et al., 2011).

20-m sprint

Following three trials of a 20-m sprint run for a specific warm-up, participants engaged in three maximal sprints over a distance of 20-m, measured using electronic timing system (Freelap BLE 424, USA). The participants were instructed to begin the test with their front foot positioned at least 0.5 m behind the starting gate. The test was initiated at a self-determined time, and the time taken to complete the 20-m sprint was recorded to the nearest 0.01 seconds. A three-minute rest interval was allocated between each attempt, and the average sprint performance values of the athlete were chosen for subsequent analysis (Rimmer and Sleivert, 2000).

Agility T-test

Upon completion of the warm-up, participants were shown a diagram (refer to Figure 1) and received a written explanation of the agility course. The researcher then accompanied the participants through the agility test to ensure they fully understood the procedure. After a series of practice runs, participants were instructed to take their positions at the starting line, indicated by cone A, and to begin the trial when prompted. At the command "GO," participants commenced their run. The time taken to finish the run was accurately recorded using electronic timing system (Freelap BLE 424, USA) positioned 0.4 m above the ground, with an accuracy of 0.01 seconds at the start/finish cone. Participants undertook three attempts, with at least two minutes of rest between each, and the average performance values of the athlete were selected for subsequent statistical analysis (Miller et al., 2006).

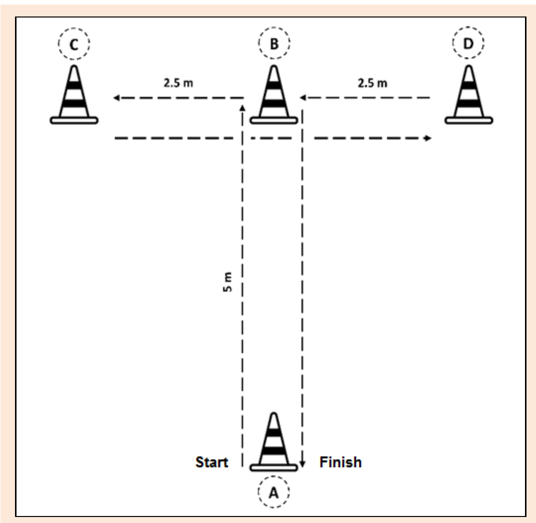

Figure 1. Agility T-test procedure.

Special Judo Fitness Test

The SJFT began with a five-minute standardized warm-up that included running, judo falling techniques (ukemi), and the repetition of throwing techniques without falling. Three athletes, matched in body weight and height, then executed the SJFT following a specific protocol: two judokas (uke) were positioned six meters apart to be thrown, while the test executor (tori) was located in the middle, three meters from each judoka. The test comprised three sessions of 15 seconds (A), 30 seconds (B), and 30 seconds (C), with 10-second intervals between each session. Throughout these sessions, the executor attempted to throw the opponents as many times as possible using the ippon seoi nage technique. Performance was evaluated by summing the total number of throws achieved in all three sessions (A + B + C). Heart rate (HR) was monitored immediately after the test and again one minute later (Polar S610i heart rate monitor) to determine the index using the designated equation. The Special Judo Fitness Test index was calculated according to the following equation: Index = (HR after + HR 1 min after)/total number of throws (Branco et al., 2022; Ceylan et al., 2022).

Strength performance

The assessment of lower body maximal strength was conducted using a 45º leg press apparatus (Nebula Fitness, Inc., Versailles, OH). Initially, each participant performed a warm-up consisting of 5 to 10 repetitions with a light resistance. Following this, the resistance was gradually increased, allowing the participant to complete 2 to 3 repetitions. Subsequently, the participant executed one repetition with each increase in load until reaching the point of voluntary failure. The aim was to achieve a maximal lift within a maximum of five attempts. A rest interval of two minutes was provided between each set (Kraemer and Fry, 1995).

Wingate anaerobic power

The Wingate anaerobic power test was conducted using a cycle ergometer (Ergomedics 874, Monark, Sweden). Following a 5-minute warm-up, participants were directed to pedal at maximum speed for 30 seconds against a resistance equivalent of 75 g per kg for each athlete's body mass (Song and Sheykhlouvand, 2024). The peak power output (P_{peak}) was determined by averaging the power over a 5-second interval, which typically coincided with the highest performance, generally occurring within the initial 5 seconds of the test. The mean power output (P_{mean}) was derived from the average power throughout the entire 30-second duration (Ceylan et al., 2018; Ning and Sheykhlouvand, 2025).

Incremental exercise test

Participants engaged in incremental exercise test on a treadmill (Technogym, Italy) to assess cardiorespiratory fitness. This evaluation utilized a breath-by-breath gas collection system (Hans Rudolph Inc., Shawnee, KS, USA). The test commenced at a speed of 6 km/hr, which was incrementally increased by 1 km/h every three minutes until the participants reached a state of voluntary exhaustion. The maximum oxygen consumption ($\dot{V}O_{2max}$) was identified as the highest value recorded within a 30-second timeframe during the test. Several criteria were employed to confirm the attainment of $\dot{V}O_{2max}$, including: a) a plateau in $\dot{V}O_2$ despite increased workload, b) a respiratory exchange ratio exceeding 1.10, c) a maximum heart rate (HRmax) reaching or surpassing 95% of the age-predicted maximum (220 - age), and d) voluntary exhaustion (Eston and Reilly, 2009; Tao et al., 2024).

Training intervention

The athletes were in the preparation phase and participated in Judo practice sessions lasting between 100 to 120 minutes from 4:00 to 7:00 P.M. In addition to their Judo sessions on Tuesdays, Thursdays, and Saturdays, the SSIT+RT and RT+SSIT groups completed their respective training interventions on Mondays, Wednesdays, and Fridays in the afternoon. The SSIT program performed three sets of 10 repetitions of 5 seconds of maximum effort running (i.e., all-out), with a recovery ratio of 1:3 (i.e., 5 seconds of all-out running followed by 15 seconds of active rest [i.e., light running]) between efforts, and a three-minute recovery period between sets, with the number of repetitions increasing by 1 each week (Boullosa et al., 2022). Additionally, the RT program employed a power-based methodology, featuring three exercises: back squat, leg press, and knee extension, performed in a circuit format for 3 sets of 8 to 12 repetitions with the intensity of 60% which conducted with maximal efforts (Arazi et al., 2014), incorporating 15 seconds of rest between trials and 90 seconds between circuits (Baltasar-Fernandez et al., 2024). A 10-minute break was observed between the two training modalities, as presented by Fyfe et al. (2016). Throughout the sessions, the athletes were closely supervised by a specialized strength and conditioning coach to ensure the precise execution of training techniques (i.e., conducting both SSIT and power-based RT as fast as possible and with maximal effort), maintaining a coach-to-athlete ratio of 1:4. Subsequent to the completion of the training intervention, the athletes undertook a cool-down routine for a duration of 15 minutes. The CON group abstained from any training intervention, continuing their established daily habits and participating exclusively in the Judo training sessions. To determine the load associated with the training interventions, the athletes' ratings of perceived exertion (RPE) were recorded on a scale of 0 to 10 (Borg, 1982). This assessment of RPE took place ten minutes following the completion of the training sessions. After the training sessions, athletes were prompted to evaluate their overall effort using a scale where 0 represented rest and 10 denoted maximal exertion.

Statistical analysis

The data were presented as mean ± standard deviation (SD). To evaluate the normality of the data for both pre-test and post-test values, the Shapiro-Wilk test was employed, while Levene's test was used to assess the homogeneity of variances. A two-factor ANOVA (time [2] × group [3]) was performed to analyze repeated measures. Upon obtaining significant F values, pairwise comparisons were conducted alongside a Bonferroni post hoc procedure to pinpoint specific significant differences while controlling for type I errors. The effect size (ES) was calculated with a 95% confidence interval (CI) to determine the magnitude of training effects, utilizing Hedge's g for all measures. According to Hopkins et al. (2009), an ES of < 0.2 is deemed trivial, 0.2 - 0.6 small, 0.6 - 1.2 moderate, 1.2 - 2.0 large, 2.0 - 4.0 very large, and > 4.0 nearly perfect. The significance threshold was established at 0.05. The coefficient of variation (CV) was computed to assess inter-individual variability in adaptations over time. Individual percent changes from pre-training to post-training were calculated for each variable, and the mean ± SD of these changes was derived (Δ% = (post - pre) / pre × 100). The CV, defined as the ratio of SD to the mean, was then determined for each variable. Furthermore, individual residuals (IRs) in changes were calculated as the square root of the squared difference between individual changes and the mean group change for each variable tested. Ultimately, inter-subject variability in adaptive responses to interventions was assessed by comparing mean residuals between groups for each variable (Sheykhlouvand and Gharaat, 2024). Furthermore, the t-test was employed to analyze the differences in RPE across the training groups.

Results

It is crucial to highlight that all participants exhibited full compliance during the entire study period, leading to the remarkable accomplishment of achieving a 100% success rate. Additionally, there were no documented cases of injuries related to the training and testing procedures.

Both training groups demonstrated statistically significant changes in the measured variables over the training period (time effect, $p = 0.001$), with effect sizes (ESs) ranging from trivial to large (Table 1, Figure 2, Figure 3 and Figure 4). In contrast, the CON group exhibited no significant changes over time.

A time-regimen interaction was observed for CMVJ (p = 0.021), 20-m linear sprint (p = 0.028), Agility T-test (p = 0.014), P_{peak} (p = 0.009), and maximal strength performance (p = 0.007), confirming that responses over time differed among groups. Therefore, post-hoc analyses were conducted to explore the source of interaction effects. The SSIT+RT group demonstrated significantly greater changes in the CMVJ (standard mean difference [SMD] = 0.62, 95% CI = -0.41 to 1.59 [Moderate], p = 0.024), 20-m linear sprint (SMD = -0.46, 95% CI = -1.42 to 0.56 [Small], p = 0.031), Agility T-test (SMD = -0.34, 95% CI = -1.33 to 0.64 [Small], p = 0.016), and P_{peak} (SMD = 0.79, 95% CI = -0.07 to 1.59 [Moderate], p = 0.009) than the RT+SSIT group over the training period (Table 1 and Figure 5). Meanwhile, the RT+SSIT group showed greater adaptations in the maximal strength performance (SMD = 0.14, 95% CI = -0.84 to 1.12 [Trivial], p = 0.007) than the SSIT+RT group across the training period (Figure 5).

No statistically significant differences were detected between the SSIT+RT and RT+SSIT groups in SJFT (SMD = -0.15, 95% CI = -1.13 to 0.84, $p = 0.726$; trivial), P_{mean} (SMD = -0.07, 95% CI = -1.04 to 0.92, $p = 0.842$; trivial), and VO_2max (SMD = 0.13, 95% CI = -0.86 to 1.10, $p = 0.897$; trivial) over time (Figure 5).

Over the training intervention, both the SSIT+RT (7.8 ± 0.5) and RT+SSIT (7.7 ± 0.6) groups demonstrated similar levels of RPE, and no significant (p = 0.706) differences were found between them.

Table 1. Performance changes in the experimental groups from the pre- to post-intervention (mean ± SD).

Variables	Hedge's g (95 % CI)		% changes	Residuals in individual % change	CV
Vertical jump (cm)					
SSIT+RT	1.58 (0.46 to 2.70)	Large	12.1 ± 1.9*#	1.51	16.2
RT+SSIT	0.85 (-0.18 to 1.87)	Moderate	6.5 ± 1.7*	1.39	26.7
20-m sprint (sec)					
SSIT+RT	-1.22 (-2.29 to -0.15)	Large	-6.6 ± 2.6*#	1.96	-39.3
RT+SSIT	-0.53 (-1.53 to 0.46)	Small	-4.2 ± 2.2	1.74	-53.1
Agility T-test (sec)					
SSIT+RT	-1.12 (-2.17 to -0.06)	Moderate	-5.6 ± 2.2*#	1.88	-39.5
RT+SSIT	-0.46 (-1.46 to 0.53)	Small	-3.2 ± 2.2*	1.85	-68.1
Lower body strength (kg)					
SSIT+RT	0.15 (-0.84 to 1.13)	Trivial	4.1 ± 2.7*	2.31	67.7
RT+SSIT	0.21 (-0.78 to 1.19)	Small	6.3 ± 3.1*§	2.49	49.9
SJFT (index)					
SSIT+RT	-0.91 (-1.94 to 0.12)	Moderate	-4.5 ± 2.3*	1.94	-51.9
RT+SSIT	-0.90 (-1.93 to 0.13)	Moderate	-4.2 ± 2.1*	1.81	-48.5
P_{peak} (w)					
SSIT+RT	1.74 (0.59 to 2.89)	Large	9.7 ± 1.7*#	1.41	18.1
RT+SSIT	1.18 (0.12 to 2.24)	Moderate	5.8 ± 1.8*	1.41	31.6
P_{mean} (w)					
SSIT+RT	0.98 (-0.06 to 2.02)	Moderate	8.6 ± 2.1*	1.61	24.2
RT+SSIT	1.11 (0.06 to 2.17)	Moderate	8.5 ± 2.1*	1.53	23.9
VO_{2max} (mL.kg^{-1}.min^{-1})					
SSIT+RT	1.17 (0.11 to 2.24)	Moderate	5.8 ± 2.0*	1.41	35.3
RT+SSIT	1.03 (-0.01 to 2.07)	Moderate	5.8 ± 2.1*	1.73	36.4

* Significantly greater changes over the training period (p < 0.05); # Significantly greater changes than RT+SSIT group (p < 0.05); § Significantly greater changes than SSIT+RT group (p < 0.05).

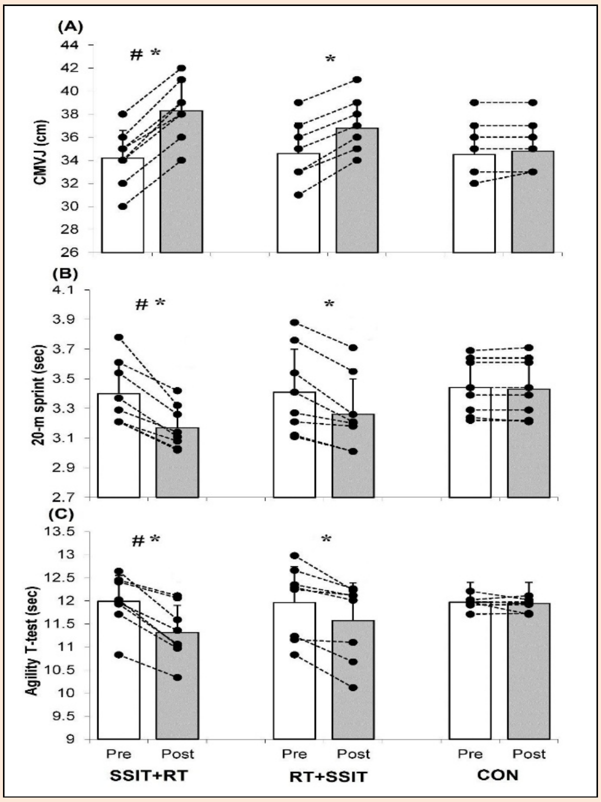

Figure 2. **Pre to post-intervention changes in the CMVJ, 20-m sprint and Agility T-test (mean ± SD).** * Significant changes over the training period ($p < 0.05$). # Significantly greater changes than RT+SSIT group over the training period.

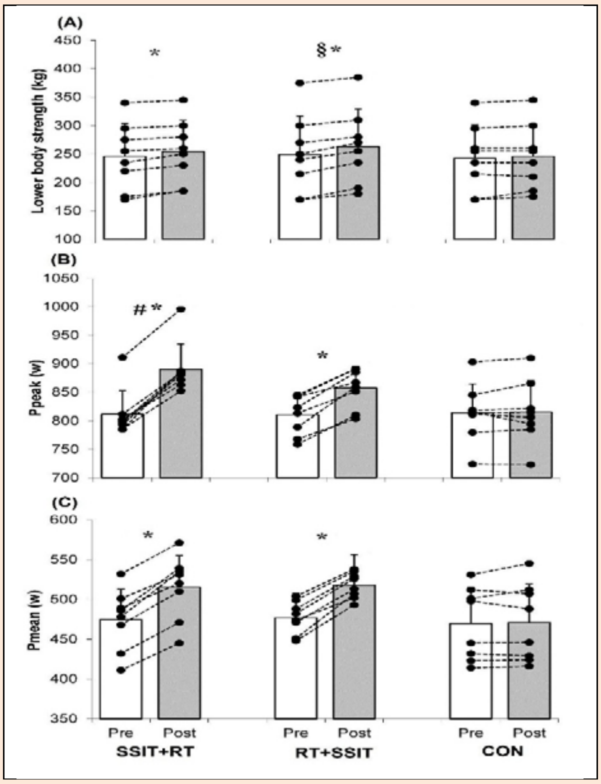

Figure 3. **Pre to post-intervention changes in the lower body strength, Ppeak and Pmean (mean ± SD).** * Significant changes over the training period ($p < 0.05$). # Significantly greater changes than RT+SSIT group over the training period. § Significantly greater changes than SSIT+RT group over the training period

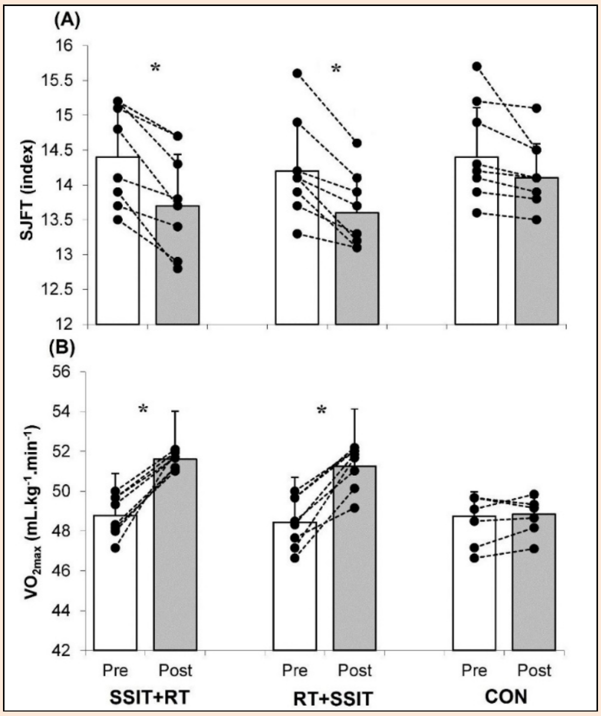

Figure 4. **Pre to post-intervention changes in the SJFT and VO2max (mean ± SD).** * Significant changes over the training period ($p < 0.05$).

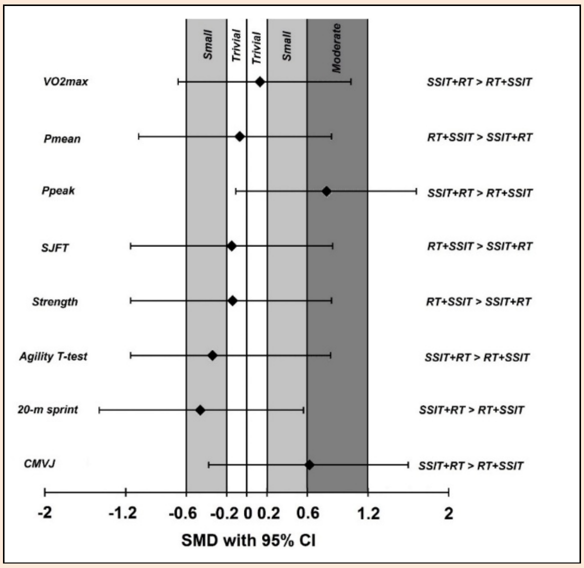

Figure 5. **Standard mean difference (SMD) with 95% CI for the SSIT+RT vs. RT+SSIT groups at post-intervention.**

Discussion

This study aimed to examine the influence of different combinations of SSIT and RT programs (i.e., SSIT+RT vs. RT+SSIT) on the physical fitness attributes of Judo athletes following a 6-week training duration. Our findings indicated that Judo training alone (CON group) did not induce meaningful effects on performance adaptations and incorporating training intervention should be included for adaptations during the preparation phase in Judo athletes. Both the SSIT+RT and RT+SSIT groups indicated significant and trivial to large ES in the magnitude of changes in all variables from pre- to post-intervention, while the SSIT+RT group demonstrated greater adaptive responses in the vertical jump, 20-m linear sprint, Agility T-test and P_{peak} than the RT+SSIT group. Meanwhile, the RT+SSIT group showed more adaptations in maximal strength performance than the SSIT+RT group at post-intervention. However, both groups demonstrated similar adaptive responses in the SJFT, P_{mean} and VO_{2max}.

In this research, the SSIT+RT and RT+SSIT groups exhibited significant enhancements in the bio-motor abilities of Judo athletes, as assessed by vertical jump, 20-m linear sprint, and Agility T-test. These results are in line with previous studies that indicated a beneficial transfer of various combinations of RT and AT on bio-motor abilities across different populations (Glowacki et al., 2004; Cadore et al., 2012; Da Silva et al., 2020; Gao and Yu, 2023). The initial mechanisms responsible for the observed performance improvements during the short-term training phase (i.e., less than 6 weeks) may be attributed to neuromuscular adaptations, which include an increase in the rate of force development and firing rates, as well as the engagement of fast-twitch muscle fibers, as highlighted in prior research (Buchheit and Laursen, 2013; Aagaard et al., 2011).

Interestingly, the SSIT+RT group demonstrated greater adaptations compared to the RT+SSIT group in vertical jump performance, the 20-m linear sprint, and the Agility T-test. This suggests that the principle of specificity in the training program facilitated these adaptations. In fact, the SSIT utilized in this study lasted five seconds, aligning with the muscle fiber recruitment patterns observed during the vertical jump and 20-m sprint (Song and Deng, 2023; Sheykhlouvand and Gharaat, 2024). Furthermore, engaging in short-sprint trials with minimal rest periods can enhance stride length and buffering capacity (Boullosa et al., 2022; Yang et al., 2024), resulting in improved sprint performance and more pronounced adaptive responses in the Agility T-test. Based on the findings of our research, it can be concluded that the implementation of RT prior to SSIT is not advisable when the objective is to enhance adaptations in bio-motor abilities. The evidence suggests that introducing RT at the beginning of a training session results in a depletion of muscle glycogen and the onset of fatigue, accompanied by an increase in lactate and H^+ ions (Knuiman et al., 2015; Brooks et al., 2023). This physiological response restricts the activation of muscle fibers during SSIT, leading to less effective adaptations in comparison to when SSIT is performed initially (Buchhiet and Laursen, 2013). Furthermore, the rise in blood lactate and H^+ ions following RT may contribute to a decrease in calcium sensitivity within the muscle fibers, which is essential for effective SSIT (Theofilidis et al., 2018; Hargreaves and Spriet, 2020). This reduction leads to diminished muscle fiber engagement and firing rates during maximal effort in short-sprint trials (Wirtz et al., 2014), ultimately yielding lower adaptations than those observed in the SSIT followed by the RT group.

Significant improvements in maximal strength were observed following a 6-week training regimen for both the SSIT+RT and RT+SSIT groups. These results indicate that the integration of SSIT and RT constitutes an effective strategy for enhancing strength development (Aagaard et al., 2002; 2011; Laursen and Buchhiet, 2019). The strength gains resulting from the training can be attributed to two primary mechanisms: a) neuromuscular adaptations, which include enhanced muscular coordination, inhibition of antagonist muscles, and the activation and contraction of synergistic muscles and motor units (Aagaard et al., 2002), and b) muscle hypertrophy, characterized by increases in myofilaments, actin and myosin filaments, sarcoplasm, and connective tissue (Schoenfeld, 2010). It appears that the combination of SSIT and RT has led to strength gains through multiple mechanisms as previously outlined.

The observed greater strength gains in the RT+SSIT group compared to the SSIT+RT group indicate that initiating a training program with SSIT may restrict the physiological adaptations necessary for strength development. It is advisable to commence training sessions with RT to facilitate these adaptations. The engagement in SSIT may lead to the accumulation of metabolites in the bloodstream, which can inhibit calcium release in muscle fibers essential for power-oriented training (Boullosa et al., 2022; Wirtz et al., 2014). Consequently, this physiological response diminishes the effectiveness of the RT program, resulting in reduced strength gains for the SSIT+RT group. However, these statements are speculative, as we did not directly measure these metabolic variables which warrants further investigation. Therefore, for Judo athletes aiming to enhance strength, it is recommended to conduct RT before SSIT to achieve greater adaptations than if SSIT is performed first.

This research indicates that both the SSIT+RT and RT+SSIT groups exhibited moderate to large effect sizes in P_{peak} and P_{mean} following the training period. Previous studies have documented enhancements in anaerobic power following the combination of SIT and RT after the 8 (Ferley et al., 2020) and 16 weeks (Müller et al., 2021) of training intervention. Two primary factors appear to contribute to these improvements. Firstly, adaptations induced by SSIT and RT, such as increased calcium sensitivity and improved buffering capacity, facilitate greater recruitment of muscle fibers while maintaining lower blood lactate levels, ultimately enhancing power output (Li and Sheykhlouvand, 2025; Furrer et al., 2023; Gharaat et al., 2020; Forbes and Sheykhlouvand, 2016). Secondly, the positive correlation between jumping ability, sprinting speed, and power output suggests that the adaptations in bio-motor capabilities resulting from SSIT and RT may promote muscle fiber engagement and recruitment over the six-week training period, leading to increased power (Ceylan et al., 2022). The training sessions, characterized by maximal effort in SSIT and a power-oriented approach in RT, fostered enhancements in muscle fiber activation, which in turn resulted in adaptations at the neuromuscular junction, further contributing to the observed increases in bio-motor abilities and power output.

Additionally, the superior improvements in P_{peak} observed in the SSIT+RT group compared to the RT+SSIT group indicate that initiating training with SSIT is advisable for enhancing power performance in short-duration efforts (i.e., 5 seconds [P_{peak}]). This recommendation is grounded in the specificity of training, as athletes typically engage in 5 seconds of all-out SSIT. Conversely, starting with RT may lead to central (i.e., changes in the synaptic concentration of neurotransmitters within the central nervous system) (Minett and Duffield, 2014) and peripheral fatigue (i.e., elevation of lactate and H+ ions) (Knuiman et al., 2015; Brooks et al., 2023), which can adversely affect the performance of SSIT, which requires maximal effort (Boullosa et al., 2022; Knuiman et al., 2015). This training approach (i.e., RT+SSIT) may be more suitable when the objective is to enhance P_{mean}. In contrast, beginning with SSIT may facilitate greater muscle fiber recruitment with lower metabolite levels, resulting in improved P_{peak}. However, when the goal is to increase P_{mean}, both combinations of SSIT and RT (i.e., SSIT+RT and RT+SSIT) yield comparable outcomes. Both training methodologies appear to engage comparable aerobic metabolic pathways, as evidenced by the improvements in the SJFT and VO_{2max}, which contributed to power output performance sustained over a duration of 30 seconds. Conversely, the inclusion of SSIT in the initial segment of the training session may have facilitated superior short-term physiological adaptations, particularly in muscle phosphocreatine levels within the muscle fibers (Boullosa et al., 2022). Additionally, both combinations of SSIT and RT (i.e., SSIT+RT and RT+SSIT) could induced meaningful changes in the aerobic glycolytic pathway, resulting in similar adaptations in P_{mean}. Nevertheless, this study represents the first examination of this subject, indicating a need for further investigations to clarify the adaptations that occur with different combinations of RT and AT in various sports populations.

The findings revealed that both the SSIT+RT and RT+SSIT groups exhibited comparable and moderate training effects regarding the adaptation of aerobic capacity tests, specifically SJFT and VO_{2max}. Various forms of AT, such as continuous running, HIIT, and SSIT, have been shown to enhance aerobic metabolic conditioning, indicating that the adaptive responses in aerobic capacity are primarily influenced by the type of AT employed, while RT has a minimal impact (Aagaard et al., 2002; Cadore et al., 2012; Fyfe et al., 2016; Gao and Yu, 2023). Consequently, it can be concluded that the adaptations observed in the SJFT and VO_{2max} are predominantly attributed to SSIT, as both combinations yielded similar results. The underlying mechanisms for the adaptations in aerobic capacity resulting from SSIT and RT may involve improvements in two critical aspects of aerobic fitness: the central component, which pertains to enhanced oxygen delivery, and the peripheral component, which relates to the improved utilization of oxygen by active muscles during aerobic exercise (Song and Deng, 2023; Sheykhlouvand and Gharaat, 2024; Yang et al., 2024).

Engaging in exercise at intensities that exceed the red zone, which generally means achieving an intensity greater than 90% of $\dot{V}O_{2max}$, activates adaptive processes that contribute to the improvement of cardiorespiratory fitness (Laursen and Buchheit, 2019). Previous research has shown that conducting sprint trials at maximal effort can elicit a significant percentage of $\dot{V}O_{2max}$, likely due to the minimal recovery time between all-out efforts (Boullosa et al., 2022), thereby enhancing aerobic fitness throughout the training duration. Although the adaptations in aerobic capacity have been thoroughly documented in the studies mentioned (Yang et al., 2024), the positive effects of RT on aerobic performance adaptation is trivial. Power-based RT is often defined by its eccentric movements, which prior studies have shown can enhance cardiorespiratory fitness (Julian et al., 2018). These eccentric movements in RT may induce changes in the biomechanical characteristics of soft tissues and skeletal muscles, resulting in heightened oxygen consumption during muscle contractions. This effect, when integrated with the SSIT, can lead to significant cardiorespiratory adaptations (Yang et al., 2024). Therefore, increasing metabolic demand following eccentric actions induced by RT and the involvement of aerobic capacity through SSIT with minimal recovery periods can produce a systemic impact on the physiological processes of skeletal muscle and adaptations in the peripheral circulation (Ashcroft et al., 2024). This process could result in enhanced capillarization and angiogenesis in skeletal muscle, as well as improvements in mitochondrial respiration and the capillary-to-fiber ratio after training (Yang et al., 2024) leading to enhancements of SJFT and VO_{2max}. Collectively, these observations suggest that the integration of RT and SSIT may impose a comparable level of stress on the requirements for oxygen transport and utilization (Touron et al., 2021; Gharaat et al., 2024), potentially leading to similar enhancements in aerobic capacity across both training groups.

This study presents a novel method for analyzing data to understand individual responses to SSIT and RT. As suggested in previous studies (Robinson et al., 2024; Sheykhlouvand and Gharaat, 2024; Song and Sheykhlouvand, 2024), calculating IRs in percentage change and CVs can be an effective approach to assess inter-subject variability in response to training intervention. Instead of simply reporting mean ± SD with a sample size, calculating IRs in percentage change and CVs can help identify how subjects responded to training intervention, as well as the consistency in responses across subjects. The results of this study show that incorporating SSIT in the first section of training sessions not only produced more adaptations in bio-motor abilities and P_{peak} but also induced more consistency in adaptations with reporting lower IRs and CVs. Furthermore, when comparing the two training regimes, the RT+SSIT group demonstrated greater consistency in responses to training intervention and lower inter-individual variations. Therefore, it is recommended that performing SSIT at the initial stage of the training session could induce consistency in adaptations in bio-motor abilities and P_{peak}, while initiation of RT could produce more homogeneity in adaptations of strength performance than the SSIT+RT group.

The current study presents several methodological limitations that warrant further examination. Firstly, the limited sample size of athletes (n = 8 for each group) may have impacted the statistical power of the findings. However, a priori power analysis indicates that this sample size is sufficient for achieving adequate statistical power (Franchini et al., 2016). Secondly, the scope of this research is restricted to male Judo athletes, necessitating further studies to determine whether these findings can be extrapolated to other sports, such as basketball or handball, or to female athletes. Lastly, the sample size is insufficient to separately analyze RT and SSIT to compare combined training effects, which should be addressed in future research. Furthermore, the lack of laboratory measurements regarding alterations in blood pH, lactate levels, and neuromuscular adaptations (such as EMG) constrains the study's capacity to assess the metabolic conditioning and muscular adaptations that took place in Judo athletes. To strengthen our conclusions, subsequent investigations should consider these factors. Therefore, we recommend that subsequent studies investigate these areas within various athletic populations or assess different training modalities.

Conclusion

The findings of the present study demonstrated that a 6-week combination of power-based RT and SSIT effectively enhanced lower-body performance in male Judo athletes, regardless of exercise order. Beginning sessions with SSIT yielded superior improvements in explosive performance, including jumping, sprinting, change of direction, and peak power, whereas initiating with RT resulted in greater strength gains. These findings emphasize the importance of sequencing in combined training, allowing coaches to align session order with specific performance goals during the preparatory phase.

Acknowledgements

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. The authors have no conflict of interest to declare. The authors declare that no Generative AI or AI-assisted technologies were used in the writing of this manuscript.

References

Aagaard, P., Andersen, J. L., Bennekou, M., Larsson, B., Olesen, J. L., Crameri, R. and Kjaer, M. (2011) Effects of resistance training on endurance capacity and muscle fiber composition in young top-level cyclists. *Scandinavian Journal of Medicine and Science in Sports* **21**(**6**), e298-e307. https://doi.org/10.1111/j.1600-0838.2010.01283.x

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P. and Dyhre-Poulsen, P. (2002) Increased rate of force development and neural drive of human skeletal muscle following resistance training. *Journal of Applied Physiology* **93**(**4**), 1318-1326. https://doi.org/10.1152/japplphysiol.00283.2002

Arazi, H., Asadi, A. and Roohi, S. (2014) Enhancing muscular performance in women: Compound versus complex, traditional resistance and plyometric training alone. *Journal of Musculoskeletal Research* **17**(**2**), 1450007. https://doi.org/10.1142/S0218957714500079

Ashcroft, S. P., Stocks, B., Egan, B. and Zierath, J. R. (2024) Exercise induces tissue-specific adaptations to enhance cardiometabolic health. *Cell Metabolism* **36**(**2**), 278-300. https://doi.org/10.1016/j.cmet.2023.12.008

Baltasar-Fernandez, I., Soto-Paniagua, H., Alcazar, J., Uceta Espinosa, M. I., Alegre, L. M., Gracía-García, F. J. and Losa-Reyna, J. (2024) Long-term effects of a 6-week power-based resistance training and fast walking interval training program on physical function, muscle power. *Gerontology* **70**(**7**), 701-714. https://doi.org/10.1159/000536363

Bonato, M., Rampichini, S., Ferrara, M., Benedini, S., Sbriccoli, P., Merati, G. and La Torre, A. (2015) Aerobic training program for the enhancements of HR and VO2 off-kinetics in elite judo athletes. *Journal of Sports Medicine and Physical Fitness* **55**(**11**), 1277-1284. https://pubmed.ncbi.nlm.nih.gov/25359131/

Borg, G. A. (1982) Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise* **14**(**5**), 377-381. https://doi.org/10.1249/00005768-198205000-00012

Boullosa, D., Dragutinovic, B., Feuerbacher, J. F., Benítez-Flores, S., Coyle, E. F. and Schumann, M. (2022) Effects of short sprint interval training on aerobic and anaerobic indices: A systematic review and meta-analysis. *Scandinavian Journal of Medicine and Science in Sports* **32**(**5**), 810-820. https://doi.org/10.1111/sms.14133

Branco, B. H., Marcondes, V. A., de Paula Ramos, S., Badilla, P. V. and Andreato, L. V. (2022) Effects of supplementary strength program on generic and specific physical fitness in cadet judo athletes. *Journal of Strength and Conditioning Research* **36**(**10**), 2816-2823. https://doi.org/10.1519/JSC.0000000000003983

Brito, A. D. F., Soares, Y. M. and Silva, A. S. (2019) Concurrent training or combined training? *Revista Brasileira de Medicina do Esporte* **25**(**2**), 105-106. https://doi.org/10.1590/1517-869220192502123895

Brooks, G. A., Osmond, A. D., Arevalo, J. A., Duong, J. J., Curl, C. C., Moreno-Santillan, D. D. and Leija, R. G. (2023) Lactate as a myokine and exerkine: Drivers and signals of physiology and metabolism. *Journal of Applied Physiology* **134**(**3**), 529-548. https://doi.org/10.1152/japplphysiol.00497.2022

Buchheit, M. and Laursen, P. B. (2013) High-intensity interval training, solutions to the programming puzzle—Part I. *Sports Medicine* **43**, 313-338. https://doi.org/10.1007/s40279-013-0029-x

Cadore, E. L., Izquierdo, M., Alberton, C. L., Pinto, R. S., Conceição, M., Cunha, G. and Kruel, L. F. M. (2012) Strength prior to endurance intra-session exercise sequence optimizes neuromuscular and cardiovascular gains in elderly men. *Experimental Gerontology* **47**(**2**), 164-169. https://doi.org/10.1016/j.exger.2011.11.013

Ceylan, B., Gurses, V. V., Mustafa Sakir, A., Baydil, B. and Franchini, E. (2018) Anthropometric profile, Wingate performance and special judo fitness levels of Turkish Olympic judo athletes. *Ido Movement for Culture. Journal of Martial Arts Anthropology* **18**(**3**), 15-20.

Ceylan, B., Šimenko, J. and Balcı, Ş. S. (2022) Which performance tests best define the Special Judo Fitness Test classification in elite judo athletes? *Journal of Functional Morphology and Kinesiology* **7**(**4**), 101. https://doi.org/10.3390/jfmk7040101

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V. and Serrão, J. C. (2017) The countermovement jump to monitor neuromuscular status: A meta-analysis. *Journal of Science and Medicine in Sport* **20**(**4**), 397-402. https://doi.org/10.1016/j.jsams.2016.08.011

da Silva, L. S., Neto, N. R. T., Lopes-Silva, J. P., Leandro, C. G. and Silva-Cavalcante, M. D. (2022) Training protocols and specific performance in judo athletes: A systematic review. *Journal of Strength and Conditioning Research* **aop**. https://doi.org/10.1519/JSC.0000000000004015

Da Silva, M. A. R., Baptista, L. C., Neves, R. S., De França, E., Loureiro, H., Lira, F. S. and Martins, R. A. (2020) The effects of concurrent training combining both resistance exercise and high-intensity interval training or moderate-intensity continuous training on metabolic syndrome. *Frontiers in Physiology* **11**, 572. https://doi.org/10.3389/fphys.2020.00572

Eston, R. and Reilly, T. (2009) *Kinanthropometry and exercise physiology laboratory manual: Tests, procedures and data*. 3rd Edn. Routledge, London, 205-207. https://doi.org/10.4324/9780203868744

Ferley, D. D., Scholten, S. and Vukovich, M. D. (2020) Combined sprint interval, plyometric, and strength training in adolescent soccer players: Effects on measures of speed, strength, power, change of direction, and anaerobic capacity. *Journal of Strength and Conditioning Research* **34**(**4**), 957-968. https://doi.org/10.1519/JSC.0000000000003476

Forbes, S. C. and Sheykhlouvand, M. (2016) A review of the physiological demands and nutritional strategies for canoe polo athletes. *Sports Nutrition and Therapy* **1**, 116. https://doi.org/10.4172/2473-6449.1000116

Franchini, E., Artioli, G. G. and Brito, C. J. (2013) Judo combat: Time-motion analysis and physiology. *International Journal of Performance Analysis in Sport* **13**(**3**), 624-641. https://doi.org/10.1080/24748668.2013.11868676

Franchini, E., Fukuda, D. H. and Lopes-Silva, J. P. (2020) Tracking 25 years of judo results from the World Championships and Olympic Games: Age and competitive achievement. *Journal of*

Sports Sciences **38**(**13**), 1531-1538. https://doi.org/10.1080/02640414.2020.1747265

Franchini, E., Julio, U. F., Panissa, V. L., Lira, F. S., Gerosa-Neto, J. and Branco, B. H. (2016) High-intensity intermittent training positively affects aerobic and anaerobic performance in judo athletes independently of exercise mode. *Frontiers in Physiology* **7**, 268. https://doi.org/10.3389/fphys.2016.00268

Furrer, R., Hawley, J. A. and Handschin, C. (2023) The molecular athlete: Exercise physiology from mechanisms to medals. *Physiological Reviews* **103**(**3**), 1693-1787. https://doi.org/10.1152/physrev.00017.2022

Fyfe, J. J., Bartlett, J. D., Hanson, E. D., Stepto, N. K. and Bishop, D. J. (2016) Endurance training intensity does not mediate interference to maximal lower-body strength gain during short-term concurrent training. *Frontiers in Physiology* **7**, 487. https://doi.org/10.3389/fphys.2016.00487

Gao, J. and Yu, L. (2023) Effects of concurrent training sequence on VO2max and lower limb strength performance: A systematic review and meta-analysis. *Frontiers in Physiology* **14**, 1072679. https://doi.org/10.3389/fphys.2023.1072679

Gharaat, M. A., Choobdari, H. R. and Sheykhlouvand, M. (2024) Cardioprotective effects of aerobic training in diabetic rats: Reducing cardiac apoptotic indices and oxidative stress for a healthier heart. *ARYA Atherosclerosis* **20**(**2**), 50-60. https://doi.org/10.48305/arya.2024.41976.2911

Gharaat, M., Karami, S., Sheykhlouvand, M. and Rajabi, H. (2025) Regulation of angiogenic genes and endothelial progenitor cells following resistance training in elderly men. *Sport Sciences for Health* 1-13. https://doi.org/10.1007/s11332-024-01322-5

Gharaat, M. A., Kashef, M., Eidi Abarghani, L. and Sheykhlouvand, M. (2020) Effect of beta alanine on lactate level and specific performance of elite male rowers. *Journal of Sabzevar University of Medical Sciences* **27**(**1**), 73-81.

Glowacki, S. P., Martin, S. E., Maurer, A. N. N., Baek, W., Green, J. S. and Crouse, S. F. (2004) Effects of resistance, endurance, and concurrent exercise on training outcomes in men. *Medicine and Science in Sports and Exercise* **36**(**12**), 2119-2127. https://doi.org/10.1249/01.mss.0000147629.74832.52

Hargreaves, M. and Spriet, L. L. (2020) Skeletal muscle energy metabolism during exercise. *Nature Metabolism* **2**(**9**), 817-828. https://doi.org/10.1038/s42255-020-0251-4

Hernández-García, R., Torres-Luque, G. and Villaverde-Gutierrez, C. (2009) Physiological requirements of judo combat. *International SportMed Journal* **10**(**3**), 145-151.

Hopkins, W. G., Marshall, S. W., Batterham, A. M. and Hanin, J. (2009) Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise* **41**(**1**), 3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

Huang, R., Zhang, M., Huang, L., Chen, Z., Mo, Y. and Gao, Y. (2023) Effects of lower-extremity explosive strength on youth judo athletes adopting different types of power-based resistance training. *Frontiers in Physiology* **14**, 1065036. https://doi.org/10.3389/fphys.2023.1065036

Julian, V., Thivel, D., Costes, F., Touron, J., Pereira, B., Duclos, M. and Richard, R. (2018) Eccentric training improves body composition by inducing mechanical and metabolic adaptations: A promising approach for overweight and obese individuals. *Frontiers in Physiology* **9**, 352104. https://doi.org/10.3389/fphys.2018.01013

Knuiman, P., Hopman, M. T. and Mensink, M. (2015) Glycogen availability and skeletal muscle adaptations with endurance and resistance exercise. *Nutrition and Metabolism* **12**, 1-11. https://doi.org/10.1186/s12986-015-0055-9

Kraemer, W. J. and Fry, A. C. (1995) Strength testing: Development and evaluation of methodology. In: Physiological Assessment of Human Fitness. P. Maud and C. Foster, Eds. (pp. 115-138). Champaign, IL: Human Kinetics.

Laursen, P. B. and Buchheit, M. (2019) In: *Science and Application of High-Intensity Interval Training*. 1st Edn. Champaign: Human Kinetics. https://doi.org/10.5040/9781492595830

Lee, M. J. C., Ballantyne, J. K., Chagolla, J., Hopkins, W. G., Fyfe, J. J., Phillips, S. M. and Bartlett, J. D. (2020) Order of same-day concurrent training influences some indices of power development, but not strength, lean mass, or aerobic fitness in healthy, moderately-active men after 9 weeks of training. *PLoS One* **15**(**5**), e0233134. https://doi.org/10.1371/journal.pone.0233134

Li, M. and Sheykhlouvand, M. (2025) Effects of combined versus single supplementation of creatine, beta-alanine, and L-citrulline during short sprint interval training on basketball players' performance: A double-blind randomized placebo-controlled trial. *International Journal of Sports Physiology and Performance* **1**(**aop**), 1-9. https://doi.org/10.1123/ijspp.2024-0310

Miarka, B., Panissa, V. L. G., Julio, U. F., Del Vecchio, F. B., Calmet, M. and Franchini, E. (2012) A comparison of time-motion performance between age groups in judo matches. *Journal of Sports Sciences* **30**(**9**), 899-905. https://doi.org/10.1080/02640414.2012.679675

Miller, M. G., Herniman, J. J., Ricard, M. D., Cheatham, C. C. and Michael, T. J. (2006) The effects of a 6-week plyometric training program on agility. *Journal of Sports Science and Medicine* **5**(**3**), 459-464. https://pubmed.ncbi.nlm.nih.gov/24353464/

Minett, G. M. and Duffield, R. (2014) Is recovery driven by central or peripheral factors? A role for the brain in recovery following intermittent-sprint exercise. *Frontiers in Physiology* **5**, 24. https://doi.org/10.3389/fphys.2014.00024

Ning, C. and Sheykhlouvand, M. (2025) Selected immunoendocrine and physiological performance adaptations to different volume of upper-body plyometric training in national-level male volleyball players. *International Journal of Sports Physiology and Performance* **20**(**3**), 363-371. https://doi.org/10.1123/ijspp.2024-0229

Müller, D. C., Boeno, F. P., Izquierdo, M., Aagaard, P., Teodoro, J. L., Grazioli, R., and Cadore, E. L. (2021) Effects of high-intensity interval training combined with traditional strength or power training on functionality and physical fitness in healthy older men: A randomized controlled trial. *Experimental Gerontology*, **149**, 111321. https://doi.org/10.1016/j.exger.2021.111321

Nuzzo, J. L., Anning, J. H., and Scharfenberg, J. M. (2011) The reliability of three devices used for measuring vertical jump height. *Journal of Strength and Conditioning Research*, **25(9)**, 2580-2590. https://doi.org/10.1519/JSC.0b013e3181fee650

Petré, H., Löfving, P., and Psilander, N. (2018) The effect of two different concurrent training programs on strength and power gains in highly-trained individuals. *Journal of Sports Science and Medicine*, **17(2)**, 167-173. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5950732/

Pito, P. G., Cardoso, J. R., Tufano, J., and Guariglia, D. (2022) Effects of concurrent training on 1RM and VO2 in adults: systematic review with meta-analysis. *International Journal of Sports Medicine*, **43(4)**, 297-304. https://doi.org/10.1055/a-1506-3007

Rimmer, E., and Sleivert, G. (2000) Effects of a plyometrics intervention program on sprint performance. *Journal of Strength and Conditioning Research*, **14(3)**, 295-301. https://doi.org/10.1519/00124278-200008000-00009

Robinson, Z. P., Helms, E. R., Trexler, E. T., Steele, J., Hall, M. E., Huang, C. J., and Zourdos, M. C. (2024) Optimizing methodology for the detection of individual response variation in resistance training. *Sports Medicine*, **1-12**. https://doi.org/10.1007/s40279-024-02050-z

Saraiva, A. R., Reis, V. M., Costa, P. B., Bentes, C. M., e Silva, G. V. C., and Novaes, J. S. (2014) Chronic effects of different resistance training exercise orders on flexibility in elite judo athletes. *Journal of Human Kinetics*, **40**, 129. https://doi.org/10.2478/hukin-2014-0015

Schoenfeld, B. J. (2010) The mechanisms of muscle hypertrophy and their application to resistance training. *Journal of Strength and Conditioning Research*, **24(10)**, 2857-2872. https://doi.org/10.1519/JSC.0b013e3181e840f3

Sheykhlouvand, M., and Gharaat, M. (2024) Optimal homeostatic stress to maximize the homogeneity of adaptations to interval interventions in soccer players. *Frontiers in Physiology*, **15**, 1377552. https://doi.org/10.3389/fphys.2024.1377552

Song, T., and Deng, Y. (2023) Physiological and biochemical adaptations to a sport-specific sprint interval training in male basketball athletes. *Journal of Sports Science and Medicine*, **22**, 605-613. https://doi.org/10.52082/jssm.2023.605

Song, Y., and Sheykhlouvand, M. (2024) A comparative analysis of high-intensity technique-specific intervals and short sprint interval training in Taekwondo athletes: Effects on cardiorespiratory fitness and anaerobic power. *Journal of Sports Science and Medicine*, **23(3)**, 672-683. https://doi.org/10.52082/jssm.2024.672

Tao, T., Zhang, N., Yu, D., and Sheykhlouvand, M. (2024) Physiological and performance adaptations to varying rest distributions during short sprint interval training trials in female volleyball players: A comparative analysis of interindividual variability. *International Journal of Sports Physiology and Performance*, **19(10)**, 1048-1057. https://doi.org/10.1123/ijspp.2024-0104

Terzis, G., Spengos, K., Methenitis, S., Aagaard, P., Karandreas, N., and Bogdanis, G. (2016) Early phase interference between low-intensity running and power training in moderately trained females. *European Journal of Applied Physiology*, **116**, 1063-1073. https://doi.org/10.1007/s00421-016-3369-z

Theofilidis, G., Bogdanis, G. C., Koutedakis, Y., and Karatzaferi, C. (2018) Monitoring exercise-induced muscle fatigue and adaptations: Making sense of popular or emerging indices and biomarkers. *Sports*, **6(4)**, 153. https://doi.org/10.3390/sports6040153

Touron, J., Costes, F., and Coudeyre, E. (2021) Aerobic metabolic adaptations in endurance eccentric exercise and training: From whole body to mitochondria. *Frontiers in Physiology*, **11**, 596351. https://doi.org/10.3389/fphys.2020.596351

Vorup, J., Tybirk, J., Gunnarsson, T. P., Ravnholt, T., Dalsgaard, S., and Bangsbo, J. (2016) Effect of speed endurance and strength training on performance, running economy and muscular adaptations in endurance-trained runners. *European Journal of Applied Physiology*, **116**, 1331-1341. https://doi.org/10.1007/s00421-016-3356-4

Wirtz, N., Wahl, P., Kleinöder, H., and Mester, J. (2014) Lactate kinetics during multiple set resistance exercise. *Journal of Sports Science and Medicine*, **13(1)**, 73-77. https://pubmed.ncbi.nlm.nih.gov/24570608/

Yang, G., Chen, W., Qi, D., Zhang, J., and Men, Z. (2024) The effects of a 6-week plyometric and sprint interval training intervention on soccer player's physical performance. *Journal of Sports Science and Medicine*, **23(3)**, 526-536. https://doi.org/10.52082/jssm.2024.526

Youcef, K., Mokhtar, M., Adel, B., and Wahib, B. (2022) Effects of different concurrent training methods on aerobic and anaerobic capacity in U21 soccer players. *Sports Science and Health*, **23(1)**, 10-22. https://doi.org/10.7251/SSH2201010Y

Key points

- The SSIT+RT and RT+SIT methodologies are both effective in promoting adaptations in the lower-extremity physical fitness attributes of Judo athletes.
- Utilizing SSIT at the beginning of the training session is more effective than RT in facilitating increased adaptations in bio-motor abilities and Ppeak.
- Initially utilizing RT is more effective than SSIT for optimizing adaptations in strength performance.
- Additionally, in relation to adaptations in aerobic capacity, including SJFT and VO2max, no order effects were identified, and both groups exhibited similar and moderate benefits from the training regimen.

AUTHOR BIOGRAPHY

Yongbing CHEN
Employment
Dianxi University of Applied Sciences
Degree
MSc
Research interests
Physical Education, Health and Fitness
E-mail: chenyongbing001@163.com

Chunlei LI
Employment
Chengdu Institute of Physical Education
Degree
MSc
Research interests
Theory and practice of wushu and national traditional sports; Combat sport
E-mail: 13541253721@163.com

Minghao PENG
Employment
Chengdu Institute of Physical Education
Degree
MSc
Research interests
Theory and practice of wushu and national traditional sports; Combat sport
E-mail: pengminghao@163.com

Jixin SHAN
Employment
Chengdu Institute of Physical Education
Degree
MSc
Research interests
TCM treatment of bone fractures
E-mail: Sjxin2005@126.com

✉ **Chunlei Li**
School of Wushu, Chengdu Institute of Physical Education, Chengdu 610041, Sichuan, China