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ORIGINAL ARTICLE

The Comparison of 10-s Sprint Interval Training with Active Recovery at 40% and 20% VO_{2peak} on Aerobic and Anaerobic Capacity

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ABSTRACT
Background. Wingate-based sprint interval training (SIT) is effective in enhancing aerobic and anaerobic fitness. An Active Recovery (AR) during a 10-s sprint may induce physical adaptation. **Objectives.** This study compares the effect of 20% and 40% VO_{2peak} AR during SIT on aerobic and anaerobic capacity. **Methods.** Twelve healthy students participated in the study. They were randomly assigned to one of two groups: 20% active recovery group (ARG) and 40% ARG. Both groups performed a series of 10-s SIT separated by 4 minutes of AR. The sprints progressed from 4 to 6 over six sessions, separated by 2 days of rest. 20-ARG performed AR at 20%. VO_{2peak} (average VO_2 from the last 15 seconds of the incremental exercise test), 40-ARG performed AR at 40% of VO_{2peak}. Aerobic and anaerobic capacity were measured before and after training. **Results.** There was no significant difference in VO_{2peak} and maximal incremental power output (P_{max}) between 20-ARG and 40-ARG. VO_{2peak} of 20-ARG was significantly increased from pre-training ($p=0.004$, $\eta^2=0.589$), whereas VO_{2peak} of 40-ARG increased but was not significantly different. P_{max} from both groups was significantly higher than pre-training ($p=0.000$, $\eta^2=0.758$). The relative leg strength in 20-ARG was significantly increased from pre-training ($p=0.020$, $\eta^2=0.431$). Anaerobic capacity and reproducibility of power output during training were not significantly different between groups or over time. AR at 20% or 40% VO_{2peak} caused similar training effects and reproducibility of power during training. **Conclusion.** Practitioners can prescribe a 10-s Wingate-based SIT with low-intensity active recovery to enhance aerobic performance and muscle strength in healthy undergraduate students.

INTRODUCTION

Wingate-based sprint interval training (SIT) involves 4 to 6 sprints of either 10 or 30 seconds at maximum effort, with 4 minutes of rest between each sprint. Research has shown that just 2 weeks of this training can enhance mitochondrial content and function, increase maximum oxygen consumption, and improve endurance performance (1). Mitochondrial content is linked to aerobic capacity, suggesting that training can have long-term benefits (2). Increasing mitochondrial content through exercise training helps the body burn more fat and fewer carbohydrates. This reduces glycogen breakdown and lactate production during exercise while raising the lactate threshold and improving exercise tolerance (1). Burgomaster et al. (2005) reported that maximal citrate synthase (CS) activity, indicative of mitochondrial content, increased after 2 weeks of SIT (3 sessions/week) (3). Moreover, several studies have demonstrated that SIT can enhance anaerobic capacity by modulating glycolytic enzymes and muscle buffering capacity (4-7). This finding is consistent with the Systemic Review 2022, which reports that SIT protocols comprising exercise bouts of ≤ 10 seconds can enhance aerobic and anaerobic performance within only a few weeks, even with a reduced exercise dose (8). Therefore, Wingate-based SIT is a time-efficient training protocol for enhancing aerobic and anaerobic fitness (4, 9, 10).

According to previous findings, exercise intensity is crucial for increasing mitochondrial content. The rate of mitochondrial biogenesis is higher in high-intensity exercise than in low-intensity exercise (11). Therefore, an all-out effort during a sprint is an important part of a training session that can elicit mitochondrial adaptation. Larsen et al. (2016) reported that 2 weeks of Wingate-based SIT inhibited mitochondrial respiration by inactivating aconitase enzymes, resulting in a compensatory increase in mitochondrial content (12). However, rest periods during a sprint session are an equally important part of a training session. The intermittent nature of training is crucial for maximizing skeletal muscle adaptation to small volumes of high-intensity exercise with all-out efforts (13). AMP-activated protein kinase (AMPK) phosphorylation, a component of the mitochondrial biogenesis process, was more significant when the training session was divided into 1-minute intervals interspersed with rest than when performed as a continuous 30-minute session (14).

Therefore, the modality of the rest period during interval training is another factor that should be considered when performing SIT. A 2024 systematic review (15) found that interval training, interspersed with active and passive recovery, effectively improves physical fitness in both trained and untrained individuals. However, there are minor improvements in physical fitness after long-term interval exercise training. Passive recovery has a large to substantial positive effect on VO2max and body composition in healthy, untrained individuals, while active recovery has a substantial positive effect on these outcomes. Therefore, interval training interspersed with active recovery appears to be suitable for healthy, untrained individuals who exercise for recreational purposes. Unfortunately, the systematic review focuses on training programs with a training duration of at least 3 weeks. Therefore, research is required during a brief training period, such as Wingate-based SIT. Moreover, the active recovery protocols from the systematic review differ and do not mention an optimal protocol for active recovery. Therefore, finding an appropriate active recovery protocol for untrained persons during Wingate-based SIT may be helpful.

The duration and workload of the rest period during SIT were examined, and 10-s SIT bouts with 1-, 2-, and 4-min recovery periods were found to increase aerobic and anaerobic performance (4, 16). However, the optimal workload during the rest period has been a topic of discussion. Active recovery (cycling at 28–40% of VO_{2peak}) has a higher ability to maintain power production by elevating cardiorespiratory demand (heart rate and oxygen uptake) than passive recovery (17, 18). Interestingly, while active recovery induced a higher acute physiological response than passive recovery during training, the physiological adaptation following training was similar to that of passive recovery. Yamagishi and Babraj (2019) reported that the active recovery group (40% VO_{2peak}) and the passive recovery group, which consisted of 30-s sprints interspersed with 4-minute recovery over 2 weeks, similarly improved their 10-km time-trial performance. However, VO2peak and power production in both groups were not increased, which was contrary to previous findings (19). The authors suggested that a VO2peak of 40% might be too high for participants with low fitness levels. Lower recovery intensity, such as 20% VO_{2peak}, may have been more suitable for improving power production and inducing better peripheral adaptations (19). Moreover, it has been reported that the decline in average power output between the first and last sprints of active recovery at 20% VO_{2peak} was less than 40% VO_{2peak} (20). Furthermore, a 2022 study (21) reports that HIIT interspersed with 1-minute active recovery at very low intensity (<57% HR_{max}) (22) can improve cardiovascular fitness and body composition in obese middle-aged men. Therefore, active recovery at very low intensity (less than 37% of

VO_{2max} (22), which is 20% of VO_{2peak} in this study) is better for maintaining sprint performance compared to low-intensity recovery (between 37-45% of VO_{2max} (22), which is 40% of VO_{2peak} in this study).

However, the training effects between 20% and 40% VO_{2peak} were not compared. Thus, the present study compared the effect of 20% and 40% VO_{2peak} active recovery during 10-s Wingate-based sprint interval training on aerobic and anaerobic capacity. This study aims to examine the effect of 20% and 40% active recovery during 10-s Wingate-based SIT on aerobic and anaerobic capacity.

MATERIALS AND METHODS

Participants. The study was conducted with 16 undergraduate students, aged 18–25 years, who were free from musculoskeletal and cardiovascular disease and exercised for recreation 1–3 days per week. The sample size was calculated by determining the effect size at f = 1.17 (20), a significance level of 0.01, and a statistical power of 0.95. The number of participants needed for this study was eight. With a 50% attrition rate, the total sample size was sixteen. Four participants had to drop out due to personal reasons. The remaining twelve healthy undergraduate students were randomly assigned to one of two training groups: Group 20-ARG (three males and three females) and Group 40-ARG (four males and two females). All subjects were informed and signed the consent form, which had been approved by the Faculty of Allied Health Science at Thammasat University, Ethics Committee No. 2/2564.

Study Design. This study was designed as a controlled experimental study. Participants were randomly assigned to one of two groups (20-ARG and 40-ARG). The duration of the training program was conducted following the definition of Wingate-based sprint interval training (SIT) (8). Both groups performed a series of 10-s SIT, separated by 4 minutes of active recovery. The number of sprints progressed from 4 to 6 sprints over six sessions separated by 2 days of rest. Group 20-ARG performed active recovery at 20% VO_{2peak}, and 40-ARG performed active recovery at 40% VO_{2peak}. Participant characteristics, peak oxygen consumption (VO_{2peak}), and maximal incremental power output were measured before and after the training period.

All participants had to attend 10 visits. Participant characteristics and aerobic and anaerobic performance were measured in the first and second visits. The third to eighth visits were training periods (3 days per week for 2 weeks). On the ninth and tenth visits, participant characteristics and aerobic and anaerobic performance were measured after training. A timeline of this study is shown in Table 1.

Table 1. Overview of the study.

Pre training		Training (2 weeks)						Post training	
		Group: 20-ARG			Group: 40-ARG				
Day 1	Day 2	Day 3-4	Day 5-6	Day 7-8	Day 3-4	Day 5-6	Day 7-8	Day 9	Day 10
Participant characteristics measurement and aerobic performance test	Anaerobic performance test	4 sprints (10 s: 4 min)	5 sprints (10 s: 4 min)	6 sprints (10 s: 4 min)	4 sprints (10 s: 4 min)	5 sprints (10 s: 4 min)	6 sprints (10 s: 4 min)	Participant characteristics measurement and aerobic performance test	Anaerobic performance test
24 hours of recovery		48 hours of recovery between days of training			48 hours of recovery between days of training			24 hours of recovery	

20-ARG: 20% of Peak Oxygen Consumption (VO_{2peak}) -Active Recovery Group; 40-ARG: 40% of VO_{2peak} -Active Recovery Group.

Aerobic Capacity Test. The participants performed an incremental test to exhaustion on a cycle ergometer (Monark Ergomedic 894E; Monark, Varberg, Sweden) to estimate their VO_{2peak}. Participants were connected to a breath-by-breath gas analyzer (MES VO_{2max} tracker Ergospirometer, America), and the test commenced at an initial power output of 50 W, with an additional 25 W increase every minute, until volitional exhaustion or the subjects could not maintain 50 rpm (23). VO_{2peak} was calculated as the average oxygen consumption from 15 seconds of the last completed exercise phase. At the VO_{2peak} level, the perceived exertion (RPE) rating is > seven on the 0–10 scale, and the peak RER is > 1.10 (24).

The maximal incremental power output (P_{max}) was calculated from the last completed work rate + [(the fraction of time spent in the final noncompleted work rate and total time in the final state; in this study, we used 60 s per stage) multiplied by the work rate increment, in this study, we used 25 W] (25).

Anaerobic Capacity Test. The participants performed a 30-second Wingate anaerobic test using a mechanically braked cycle ergometer (model 894E bicycle ergometer, Monark, Stockholm, Sweden) with resistance corresponding to 6.7% of their body mass. The results were analyzed for peak power, relative peak power, average power output, relative average power, and fatigue index.

The participant guidelines for aerobic and anaerobic capacity testing were as follows: First, participants were instructed to abstain from food consumption, alcohol intake, and tobacco use for at least 3 hours prior to the test. Caffeine should be avoided for 12 hours prior to the test. Second, participants were required to wear appropriate athletic attire and properly fitted athletic footwear suitable for exercise testing. Third, participants should refrain from strenuous physical activities for at least 12 hours prior to the test. Moreover, participants were instructed to maintain adequate hydration for 24 hours prior to the test.

Training Session. Both training groups (20-ARG, 40-ARG) performed four to six 10-second sprints against 10% of their body mass, interspersed with 4-minute recovery periods (4). However, 20-ARG cycled at 20% VO_{2peak} during the recovery, while 40-ARG cycled at 40% VO_{2peak} during the recovery. Both groups performed their respective training protocol 3 times per week for 2 weeks (6 sessions in total), and sprint load increased with time (4 sprints for the first two sessions, five sprints for the middle two sessions, and six sprints for the last two sessions) as previously described. The duration between training sessions was 48–72 hours. Participants were instructed to refrain from strenuous physical activity during recovery between training sessions to minimize potential confounding effects.

Reproducibility Of Power Calculation. The reproducibility of power during the training was evaluated by the power drop rate across the sprints in each session. The reproducibility of power was calculated from the following equation: the reproducibility of power = [(sum of power output, either peak or average from each stage ÷ total number of sprints) divided by maximum power output] × 100 (26). Peak and average power were automatically determined through Monark software. The participants performed the post-intervention tests within 72 hours after the last training session. The order of the measurements was identical to the pre-intervention tests, and each measurement was separated by 24 hours.

Statistical Analysis. All results were expressed as Mean ± SD. The Shapiro-Wilk test was used to confirm the normal distribution for these data. Effects of training on each variable were analyzed using a 2-way analysis of variance between (group) and repeated (time) factors to see whether there was a significant main effect for time or group interaction. All statistics were analyzed using IBM SPSS Version 22.0 for Windows, with a significance level set at $p < 0.05$.

RESULTS

The researchers followed the STROBE guidelines (27), adhering to recommendations designed to enhance the quality of reporting in cross-sectional studies. Participants' characteristics, including age, weight, height, percentage of fat, relative grip and leg strength, VO_{2peak} consumption, and maximum power output, are shown in Table 2. Both groups did not differ significantly in terms of baseline relative strength and aerobic and anaerobic capacity. After 2 weeks of training, relative grip and leg strength between the groups were not significantly different (Relative grip strength (kg/BW): Time * Group Wilks' Lambda =0.991, F=0.089, p=0.771, pairwise comparison between group p=0.652; Relative Leg strength (kg/BW): Time * Group Wilks' Lambda =0.924, F=0.827, p=0.385, pairwise comparison between group p=0.750). However, the relative leg strength of the 20-ARG group was significantly higher than pre-training (Relative Leg strength (kg/BW): Time Wilks' Lambda =0.569, F=7.571, p=0.020, η^2=0.431, pairwise comparison between pre and post-training p=0.027).

Aerobic Capacity. VO_{2peak} and P_{max} were not significantly different between 20-ARG and 40-ARG after 2 weeks of training (VO_{2peak} (L/min): Time * Group Wilks' Lambda =0.929, F=0.759, p=0.404, pairwise comparison between group p=0.647; VO_{2peak} (ml/kg/min): Time * Group Wilks' Lambda =0.915, F=0.929, p=0.358 pairwise comparison between group p=0.919; P_{max}: Time * Group Wilks' Lambda =0.996, F=0.038, p=0.849, pairwise comparison between group p=0.615). However, VO_{2peak} after training was significantly higher than pre-training in 20-ARG (percent increased absolute VO_{2peak}: 47.85%, Time Wilks' Lambda =0.411, F=14.323, p=0.004, η^2=0.589, pairwise comparison between pre and post-training p=0.008; percent increased relative VO_{2peak}: 45.93%, Time Wilks' Lambda =0.421, F=13.750, p=0.004, η^2=0.579, pairwise comparison between pre and post-training p=0.008). In 40-ARG, VO_{2peak} increased after training but was not significantly different from pre-training (percent increased absolute VO_{2peak}: 22.36%, p=0.066; percent increased relative VO_{2peak}: 22.18%, p=0.081). Moreover, maximal incremental power output (P_{max}) after training was significantly higher than baseline in both groups (Time Wilks' Lambda =0.242, F=31.345, p=0.000, η^2=0.758, percent increased P_{max} of 20-ARG: 13.84%, pairwise comparison between pre and post-training p=0.003, percent increased P_{max} of 40-ARG: 14.14%, pairwise comparison between pre and post-training p=0.002). Data is shown in Table 3.

Table 2. Participant characteristics.

Parameters	**Group: 20-ARG (n=6, M=3, W=3) Mean ± SD**	**Group: 40-ARG (n=6, M=4, W=2) Mean ± SD**	**P[a,b]**
Age (years)	21.71 ± 1.17	21.00 ± 0.89	0.787[a]
Weight (kg)	60.41 ± 4.51	63.10 ± 9.86	0.558[a]
Height (cm)	167.17 ± 4.71	166.33 ± 9.58	0.852[a]
Fat (%)	21.81 ± 11.40	24.20 ± 8.56	0.691[a]
Relative grip strength (kg/BW)	0.56 ± 0.20	0.51 ± 0.07	0.604[b]
Relative Leg strength (kg/BW)	1.50 ± 0.75	1.58 ± 0.59	0.906[b]
VO_{2peak} (L/min)	1.86 ± 0.58	2.46 ± 0.89	0.199[b]
VO_{2peak} (ml/kg/min)	31.57 ± 12.61	38.36 ± 8.70	0.303[b]
Maximal incremental power output (Watt)	180.83 ± 26.34	189.83 ± 40.16	0.656[b]
Peak power (W)	609.41 ± 122.84	574.48 ± 152.93	0.672[b]
Relative peak power (W/kg)	10.26 ± 2.94	9.08 ± 1.54	0.405[b]
Average power (W)	399.96 ± 34.88	425.85 ± 121.83	0.627[b]
Relative average power (W/kg)	6.68 ± 1.10	6.68 ± 1.07	0.998[b]

20-ARG: 20% of Peak Oxygen Consumption (VO_{2peak})-Active Recovery Group; 40-ARG: 40% of VO_{2peak} -Active Recovery Group; a: Independent t-test between 2 groups; b: 2-way analysis of variance with between (group) and repeated (time) factors.

Table 3. Aerobic - Anaerobic capacities and relative strength before (pre) and after (post) 2 weeks of SIT in 20-ARG and 40-ARG.

parameters	**Group: 20-ARG**		**Group: 40-ARG**	
	Pre	**Post**	**Pre**	**Post**
Aerobic capacity				
VO_{2peak} (L/min)	1.86 ± 0.58	2.75 ± 0.81*	2.46 ± 0.89	3.01 ± 1.11
VO_{2peak} (ml/kg/min)	31.57 ± 12.61	46.07 ± 15.07*	38.36 ± 8.70	46.87 ± 11.53
Maximal incremental power output (W)	180.83 ± 26.34	205.86 ± 29.79*	189.83 ± 40.16	216.67 ± 41.47*
Anaerobic capacity				
Peak power (W)	609.41 ± 122.84	582.14 ± 108.82	574.48 ± 152.93	636.65 ± 226.77
Relative peak power (W/kg)	10.26 ± 2.94	9.76 ± 2.60	9.08 ± 1.54	9.88 ± 2.11
Average power (W)	399.96 ± 34.88	422.76 ± 43.87	425.85 ± 121.83	441.98 ± 125.33
Relative average power (W/kg)	6.68 ± 1.10	6.70 ± 1.71	6.68 ± 1.07	6.71 ± 1.31
Fatigue index (%)	61.24 ± 5.10	59.99 ± 10.87	59.69 ± 18.44	66.91 ± 12.14
Relative strength				
Relative grip strength (kg/BW)	0.56 ± 0.20	0.57 ± 0.17	0.51 ± 0.07	0.54 ± 0.09
Relative Leg strength (kg/BW)	1.50 ± 0.75	1.94 ± 1.01*	1.58 ± 0.60	1.80 ± 0.37

*: Significantly different from pre-training p<0.05; Data are expressed as mean ± SD; 20-ARG: 20% of Peak Oxygen Consumption (VO_{2peak}) -Active Recovery Group; 40-ARG: 40% of VO_{2peak} -Active Recovery Group.

Anaerobic Capacity. Peak power, relative peak power, average power, relative average power, and fatigue index were no significant different between group and time (Peak power(watt): Time * Group Wilks' Lambda =0.811, F=2.336, p=0.157, Time Wilks' Lambda =0.966, F=0.356, p=0.564; Relative peak power(watt/kg): Time * Group Wilks' Lambda =0.833, F=1.998, p=0.188, Time Wilks' Lambda =0.989, F=0.114, p =0.743; Average watt(watt): Time * Group Wilks' Lambda =0.986, F=0.140, p=0.716, Time Wilks' Lambda =0.678, F=4.746, p=0.054; Relative average power(watt): Time * Group Wilks' Lambda =1.000, F=0.001, p=0.979, Time Wilks' Lambda =0.999, F=0.014, p=0.907; Fatigue index(%): Time * Group Wilks' Lambda =0.956, F=0.456, p=0.515, Time Wilks' Lambda =0.978, F=0.227, p=0.644).

Reproducibility of Power during Training. The peak and average power reproducibility of 6 training sessions from both groups were not significantly different (Peak power reproducibility: Time * Group Wilks' Lambda =0.481, F=1.295, p=0.376, Time Wilks' Lambda =0.450, F=1.466, p=0.325; Average power reproducibility: Time* Group Wilks' Lambda =0.578, F=0.878, p=0.547, Time Wilks' Lambda =0.339, F=2.342, p=0.165) as shown in Figure 1.

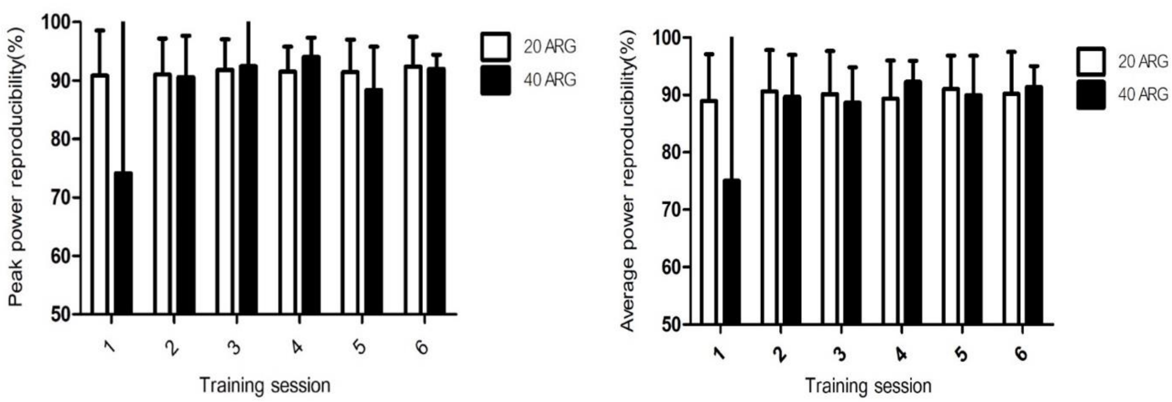

Figure 1. Bar graphs showing peak (left plot) and average (right plot) power reproducibility (%) for 20-ARG and 40-ARG.

DISCUSSION

The primary finding of this study is that active recovery at 20% and 40% VO2peak during 10-s Wingate-based SIT yields a similar training effect on both aerobic and anaerobic performance. However, only 20% of the VO_{2peak} group showed an increase in VO_{2peak} and relative leg strength after training. In the 40% VO_{2peak} group, only P_{max} increased after training. Moreover, the reproducibility of power during training was not significantly different between the groups.

Change of Aerobic Capacity after Training. According to the results, VO2peak increased in both groups; however, only 20% of the VO_{2peak} group showed a significant improvement from pre-training. The pairwise comparison of VO_{2peak} between pre and post-training in the 40% VO_{2peak} group resulted in p-values of 0.06 (VO_{2peak} (L/min)) and 0.08 (VO_{2peak} (ml/kg/min)), which were quite close to 0.05. If this study had a larger number of participants, statistical analysis might have revealed a significant difference in VO2peak between the pre- and post-training periods in the 40% VO_{2peak} group. Unfortunately, this study was conducted during the COVID-19 pandemic, and it was challenging to recruit additional participants. Another interesting point to consider is that the average VO2peak of the 20% VO2peak group in pre-training was lower than that of the 40% VO2peak group, despite statistical analysis revealing no significant difference between the groups. However, the improvement of VO_{2peak} in the 20% VO_{2peak} group was consistent with previous studies (4, 16). We assumed that a 10-s Wingate-based SIT with active recovery can enhance VO_{2peak} by increasing the mitochondrial content and function. Previous studies reported that maximal citrate synthase (CS) activity, which can indicate mitochondrial content, increased by 38% (7) and 11% (3) after 2 weeks of SIT (3 sessions/week). Unfortunately, the mitochondrial enzyme was not measured. Thus, a further study should examine the adaptations in skeletal muscle metabolic function and substrate utilization in 2 weeks of 10s sprint interval training.

P_{max}, which can indicate peripheral muscle adaptation, significantly increased from pre-training in both groups, with no difference between the groups. Jacob et al. (2011) reported that increased P_{max} after training can be primarily attributed to oxygen transport capacity (28). Thus, both training protocols can enhance the oxygen transport capacity. This finding was consistent with the study by Yamakishi et al. (2019), which reported a 5.3% increase in Pmax, although this change did not reach statistical significance. The authors speculated that it may have been caused by improvements in capillary density, resulting in improved oxygen supply and maximal endurance capacity. Therefore, 20% and 40% VO_{2peak} during 10-s Wingate-based sprint interval training are practical to improve P_{max} (19).

Change of Anaerobic Capacity after Training. Anaerobic capacity was not significantly different between the groups after training, and there was no difference from pre-training in either group. This finding is inconsistent with previous reports. Hazell et al. (2010) reported that 10-s SIT interspersed with 4-minute active recovery by unload cycle can increase anaerobic capacity (peak and average power (4). Moreover, MacDougall et al. (1998) reported that 30-s SIT interspersed with 4-minute active recovery by unload cycle can peak power output and total work during 30-s sprint cycling by increasing maximal glycolytic enzyme activity and Na^+/K^+-ATPase pump capacity (6). According to these previous findings, active recovery with unloaded cycling appears to be more effective than active recovery with loaded cycling in enhancing anaerobic capacity. However, another interesting finding from a recent study reports that passive recovery is better than active recovery for improving power (29). Mauro et al. (2024) suggest that passive recovery facilitates a more comprehensive metabolic restoration than active recovery, enabling participants to perform at maximal effort during sprint training and increase their power (29). Unfortunately, this study cannot provide a clear explanation for this finding. Therefore, further studies should examine this point in more depth.

Change of Relative Leg Strength. Leg muscle strength did not differ between the groups after training; however, the 20% VO2peak group showed a significant improvement in leg muscle strength. The improvement in muscle strength from 10-s SIT interspersed with very low active recovery in this study is consistent with the study by Mauro et al. (2024) (29). Mauro et al. found that high-intensity interval training with a very low intensity (50% HRmax) can improve hand grip strength more than passive recovery after 8 weeks of training. However, the improvement in grip strength was affected by the difference in the participants' gender. Male participants have higher improvement than female participants. Therefore, the difference between genders is another point that should be considered in further study.

However, a study reported that six sessions of 30-second SIT could increase aerobic capacity but did not improve lower-body strength (26). The training duration in the study is longer than in our study. Based on the previous finding, six sessions of 10-s SIT allowed participants to maintain peak power during training more effectively than six sessions of 30-s SIT (4). Therefore, 10-s might be sufficient for SIT to induce participants to generate high force during exercise and significantly improve muscle strength after training. However, this hypothesis needs further investigation.

Reproducibility of Power during Training. A previous study suggested that a target of 40% VO2peak might be too high for participants with low fitness levels, and a lower recovery intensity, such as 20% VO_{2peak}, might have been more suitable for improving power production and inducing better peripheral adaptations (19). We assumed that active recovery at 20% during 10-s Wingate-based SIT would allow participants to maintain a higher percentage of peak and average power during training than at 40% VO2peak; however, the statistical analysis revealed no difference between the groups. However, the reproducibility of the peak and average power of 40-ARG was lower than that of 20-ARG in the first training session, but it increased to match 20-ARG in the next training session. Participants who performed high active recovery loads needed more time to familiarize themselves with the training program. However, after the first training session, active recovery at 20% and 40% VO_{2peak} induced a similar effect on the reproducibility of power during training.

Limitation. There were two limitations in this study. Firstly, we did not measure metabolic enzymes in muscle. Hence, we cannot confirm that the training protocol can increase mitochondrial content and function after training. Secondly, the number of participants in this study is limited due to the research being conducted during the COVID-19 pandemic. However, the sample size was calculated using the G*power program version 3.0.10. The sample size was calculated by determining the effect size at f=1.17 (20), a significance level of 0.01, and a statistical power of 0.95. The number of participants needed for this study was 8. With a 50% attrition rate, the total sample size was 16. Therefore, a further study should include the measurement of muscle metabolic enzymes and recruit a larger number of participants from diverse populations, such as those with different genders, ages, ethnicities, or specific athletic groups, to confirm this finding.

CONCLUSION

Active recovery at 20% and 40% of VO2peak during a 10-s Wingate-based SIT causes a similar training effect on both aerobic and anaerobic performance. However, only the 20% VO_{2peak} group showed increased VO_{2peak} and relative leg strength after training, while the 40% VO_{2peak} group could only increase P_{max}. Furthermore, the number of participants was limited, which may affect the generalizability of the findings. The efficacy of this training protocol may be specifically applicable to healthy college-aged individuals with physical fitness levels comparable to those of our study cohort.

APPLICABLE REMARKS

- This study suggests that low-intensity active recovery effectively increases aerobic performance and muscle strength, similar to low-intensity exercise.
- When 10-s Wingate-based SIT is prescribed for healthy undergraduate students, coaches and sports scientists can use very low-intensity active recovery during the recovery period of interval training.

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AUTHORS' CONTRIBUTIONS

Study concept and design: Supattra Silapabanleng, Sairag Saadprai, Piriya Suwondit. Acquisition of data: Supattra Silapabanleng, Sairag Saadprai, Vinitha Puengtanom, Supasin Wilaskhampee, Piriya Suwondit. Analysis and interpretation of data: Supattra Silapabanleng, Sairag Saadprai, Piriya Suwondit. Drafting the manuscript: Supattra Silapabanleng, Sairag Saadprai, Piriya Suwondit. Critical revision of the manuscript for important intellectual content: Supattra Silapabanleng, Sairag Saadprai, Piriya Suwondit. Statistical analysis: Supattra Silapabanleng, Sairag Saadprai, Piriya Suwondit. Administrative, technical, and material support: Supattra Silapabanleng, Sairag Saadprai, Piriya Suwondit. Study supervision: Supattra Silapabanleng, Sairag Saadprai, Piriya Suwondit.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

The authors have no financial interests related to the material in the manuscript.

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ETHICAL CONSIDERATION

This study's protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki, which was approved by the Faculty of Allied Health Science at Thammasat University, Ethics Committee No. 2/2564. All participants read and signed the consent form before participating in the study.

The data collection took place in a secure location, specifically in the MS109 room of the Main Stadium building, Department of Sports Science and Development, Faculty of Allied Health Sciences, Thammasat University, Rangsit Campus. Research documents are stored there; no research was conducted outside Thammasat University. Access to the research data was restricted to the researchers and assistants. The primary location for accessing this data is the MS201 room in the Main Stadium building at the Department of Sports Science and Development, Faculty of Allied Health Sciences, Thammasat University, Rangsit Campus.

Furthermore, all participant information was kept confidential. Only the researchers can analyze, present, or publish the research findings without identifying any participants in any format. All data, including assessment documents and electronic files, will be destroyed within five years after the completion of data collection using a document shredder at the Department of Sports Science and Sports Development, Thammasat University, Rangsit Campus. For electronic data, the researchers will delete the information from the computer used for data recording.

ROLE OF THE SPONSOR

The funding organizations are public institutions and have no role in the design and conduct of the study, the collection, management, and analysis of the data, or the preparation, review, and approval of the manuscript.

ARTIFICIAL INTELLIGENCE (AI) USE

The authors declare that they have not used any generative artificial intelligence to write this manuscript or create images, graphics, tables, or corresponding captions.

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