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ORIGINAL ARTICLE

Comparative 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' rest. 20-ARG performed AR at 20%. VO_{2peak} (average VO_2 from last 15 s of incremental exercise test), 40-ARG performed AR at 40% 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 during training were not significantly different between groups and time. AR at 20% or 40% VO_{2peak} caused similar training effects and reproducibility of power during training. **Conclusion.** Practitioners can prescribe 10-s Wingate-based SIT with low-intensity active recovery to increase aerobic performance and muscle strength for 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 and suggests that training can have long-term benefits (2). Increasing mitochondrial content through exercise training helps the body burn more fat and less 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 showed that SIT can improve anaerobic capacity by changing glycolytic enzymes and muscle buffering capacity (4-7). This is consistent with the Systemic Review 2022, which reports that SIT protocols comprised of exercise bouts of ≤ 10 s can enhance aerobic and anaerobic performances within only a few weeks and 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 important to increase 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 compensation for 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 important to maximize skeletal muscle adaptation to small volumes of high-intensity exercise with all-out efforts (13). AMP-activated protein kinase (AMPK) phosphorylation, a part of the process of mitochondrial biogenesis, was more significant when the training session was divided into 1 min intervals interspersed with rest than performed as a continuous 30 min session (14). Therefore, the modality of the rest period during interval training is another factor that should be considered when performing SIT. A systemic review in 2024 (15) reviewed that interval training interspersed with active and passive recovery effectively improves physical fitness in trained and untrained persons. However, there are minor improvements in physical fitness after long-term interval exercise training, with passive recovery in healthy untrained persons and active recovery having large to substantial positive effects on VO_{2max} and body composition in healthy untrained persons. Therefore, interval training interspersed with active recovery seems suitable for healthy, untrained who exercise for recreation. Unfortunately, the systemic 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, active recovery protocols from the systemic review are different and did not mention the optimal protocol of 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 discussed. 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 after training was similar to passive recovery. Yamagishi and Babraj (2019) reported that the active recovery group (40% VO_{2peak}) and passive recovery group of 30-s sprints interspersed with 4-minute recovery over 2 weeks similarly improved 10-km time-trial performance but that VO_{2peak} and power production in both groups were not increased which was contrary to previous findings (19). The authors suggested that 40% VO_{2peak} might be too heavy for participants with low fitness levels. Lower recovery intensity, such as 20% VO_{2peak}, might have been more suitable for improving power production and inducing more excellent 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 study in 2022 (21) reports that HIIT interspersed with 1-min 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 started with 16 undergraduate students, 18–25 years old, without musculoskeletal or cardiovascular disease, and who 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 1 of 2 training groups: group 20-ARG (3 males, 3 females) and group 40-ARG (4 males, 2 females). All subjects were informed and signed the consent form that the Faculty of Allied Health Science had approved, Thammasat University Ethics Committee No.2/2564.

Study Design. This study was designed as a controlled experimental study. Participants were randomly assigned into 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 6 sessions separated by 2 days 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 training.

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 recovery		48 hours recovery between days of training			48 hours recovery between days of training			24 hours 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 >7 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) against a resistance corresponding to 6.7% of an individual's body mass. The results were analyzed for peak power, relative peak power, average power output, relative average power, and fatigue index.

The participant guidelines before aerobic and anaerobic capacity testing were conducted as follows: First, participants were instructed to abstain from food consumption, alcohol intake, and tobacco use for at least 3 hours before 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 avoid strenuous physical activities for at least 12 hours before the test. Moreover, participants were instructed to maintain adequate hydration during the 24 hours before the test.

Training Session. Both training groups (20-ARG, 40-ARG) performed four to six 10-second sprints against 10% of body mass interspersed with 4-minute recovery (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 2 sessions, 5 sprints for the mid 2 sessions, and 6 sprints for the last 2 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 sessions. 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 run on IBM SPSS Version 22.0 for Windows, and the significance level was 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 were not significantly different regarding 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.

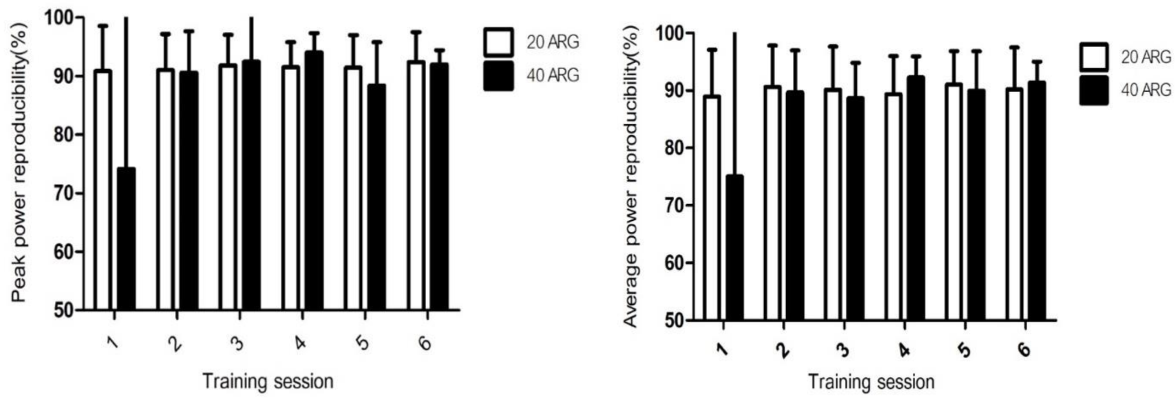

Figure 1. Bar graphs showing peak (left plot) and average (right plot) power reproducibility (%) for 20-ARG and 40-ARG.

DISCUSSION

The main finding of this study is that active recovery at 20% and 40% VO_{2peak} during 10-s Wingate-based SIT provides a similar training effect on aerobic and anaerobic performance. However, only 20% of the VO_{2peak} group showed increased 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 result, VO_{2peak} increased in both groups, but 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 more significant number of participants, then statistical analysis might have found a significant difference in VO_{2peak} between pre and post-training in the 40% VO_{2peak} group. Unfortunately, this study was conducted during the COVID-19 epidemic, and it was not easy to recruit more participants. Another interesting point that must be considered is that the average VO_{2peak} of the 20% VO_{2peak} group in pre-training was lower than in the 40% VO_{2peak} group, even though the statistical analysis found 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 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, and there was 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 of Yamakishi et al. (2019), in which a 5.3% increase in P_{max} was found, 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 increased maximal glycolytic enzyme activity and Na^+/K^+-ATPase pump capacity (6). According to these previous findings, active recovery with unload cycling seems 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) assume that passive recovery helps achieve a broader metabolic restoration than active recovery, allowing the participants to perform the maximal effort during sprint training and increasing power (29). Unfortunately, this study cannot clearly explain this finding. Therefore, further studies should examine this point in more depth.

Change of Relative Leg Strength. Leg muscle strength was not different between the groups after training, but the 20% VO_{2peak} group showed significant improvement. The improvement of muscle strength from 10-s SIT interspersed with very low active recovery in this study is consistent with Mauro et al. study (2024) (29). Mauro et al. found that high-intensity interval training with very low intensity (50%HR_{max}) can improve hand grip strength higher than passive recovery after 8 weeks of training. However, the improvement in grip strength was affected by the difference in the participant's 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 6 sessions of 30-s 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. From the previous finding, six sessions of 10-s SIT allowed participants to maintain peak power during training better 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 40% VO_{2peak} might be too heavy 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 more excellent 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 40% VO_{2peak}, but the statistical analysis revealed no difference between the groups. However, the reproducibility of the peak and average power of 40-ARG was lower than 20-ARG in the first training session, but it increased to 20-ARG in the next training session. Participants who performed high active recovery load needed more time to familiarize themselves with the training program, but after the first training time, 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 because this research was conducted during COVID-19. 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 add the measurement of muscle metabolic enzymes and recruit a more significant number of participants from diverse populations, such as gender, age, ethnicity, or specific groups of athletes, to confirm this finding.

CONCLUSION

Active recovery at 20% and 40% VO_{2peak} during 10-s Wingate-based SIT causes a similar training effect on 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} after training. 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 like low intensity. 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 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 the Faculty of Allied Health Science approved, Thammasat University Ethics Committee No.2/2564. All participants read and signed the consent form before participating in the study.

The data collection occurred in a secure location, specifically at MS109 room, 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, collection, management, and analysis of the data or 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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