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Effects of work-matched high-intensity intermittent cycling training with different loads and cadences on Wingate anaerobic test performance in university athletes

Nobuyasu Tomabechi[1,2*], Kazuki Takizawa[3], Keisuke Shibata[2,4] and Masao Mizuno[5,6]

[1] *Sports Training Center, Nippon Sport Science University, 7-1-1 Fukasawa, Setagaya-ku, Tokyo 158-8508, Japan*
[2] *Graduate School of Education, Hokkaido University, Kita 11, Nishi 7, Kita-ku, Sapporo, Hokkaido 060-0811, Japan*
[3] *Institute of Physical Development Research, Nishi 5, Minami 1, Chuo-ku, Sapporo, Hokkaido 060-0061, Japan*
[4] *Department of Sustainable Agriculture, College of Agriculture, Food and Environment Sciences, Rakuno Gakuen University, 582 Bunkyodai-Midorimachi, Ebetsu, Hokkaido 069-8501, Japan*
[5] *Faculty of Education, Hokkaido University, Kita 11, Nishi 7, Kita-ku, Sapporo, Hokkaido 060-0811, Japan*
[6] *Hachinohe Gakuin University, 13-98 Mihono, Hachinohe, Aomori 031-8588, Japan*

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Abstract Work-matched high-intensity intermittent cycling training (HIICT) reportedly improves $\dot{V}O_{2max}$ regardless of the combination of loads and cadences. However, the effect of work-matched HIICT with different combinations of loads and cadences on anaerobic work capacity is unknown. This study aims to investigate the effects of work-matched HIICT with different loads and cadences on Wingate anaerobic test (WAnT) performance, which is an index of anaerobic work capacity. University athletes performed HIICT either with high-load / 60 rpm (HL60, n = 8) or low-load / 120 rpm (LL120, n = 8). HIICT consisted of eight sets of pedaling for 20 s with 10 s of passive rest between each set. Initial exercise intensity was set at 135% of $\dot{V}O_{2peak}$ and decreased by 5% after every two sets. HIICT was performed for 18 sessions during the 6-week period. Pre and post the training period, peak power, peak rpm, average power, and time to reach peak power during WAnT and $\dot{V}O_{2peak}$ were measured. According to two-way analysis of variance (time × group), the main effect of time was observed in $\dot{V}O_{2peak}$, peak power, peak rpm, and average power during WAnT ($p < 0.05$). However, time × group interaction was not observed for any indices ($p > 0.05$). Conversely, time × group interaction was observed in time to reach peak power during WAnT, and significantly shortened only in HL60 ($p < 0.05$). These results suggest the effectiveness of work-matched HIICT with high-load / low cadence on WAnT performance.
Keywords : $\dot{V}O_{2peak}$, time to reach peak power, peak power, average power

Introduction

High-intensity intermittent training (HIIT) is defined as a training method that repeats high-intensity exercise intermittently with submaximal or near maximal effort[1]. HIIT is also considered a time-efficient endurance training method compared to traditional moderate-intensity continuous training[2-4]. HIIT is performed using various exercise modes such as cycling, running, aquatic treadmill running, jumping rope, swimming, and kettlebell training[5]. The eccentric contraction phase that causes muscle damage is shorter during cycling exercises than during running exercise[6]. Stress on the anterior cruciate ligament in the knee joint during cycling exercises is also lower than that in other exercises, such as leg extensions and squats[7]. Therefore, to improve the endurance capacity of athletes safely and more efficiently, it is important to elucidate more efficient HIIT methods using a cycle ergometer.

High intensity intermittent cycling training (HIICT) with low-load / high cadence may improve anaerobic work capacity (e.g. Wingate anaerobic test [WAnT] performance) more than HIICT with high-load / low cadence under work-matched conditions. Work volume during cycling exercise (J) is calculated by multiplying load (kp), cadence (rpm), and exercise time. Therefore, it can be used for cycling training in either high-load / low cadence or low-load / high cadence pattern under work matched conditions[8]. Tomabechi et al.[9] reported that HIICT with either high-load / 60 rpm or low-load / 120 rpm equally improved $\dot{V}O_{2max}$ under work-matched conditions. However, the effect of work-matched HIICT with either

*Correspondence: nobuyasu.tomabechi@gmail.com

high-load / low cadence or low-load / high cadence on anaerobic work capacity is unknown. Anaerobic work capacity can be easily evaluated using WAnT that involves a maximal sprint for 30 seconds. There is a significant correlation between anaerobic work capacity assessed by mean power during WAnT and repeated sprint performance[10]. Hence, it is important to clarify the effects of work-matched HIICT with different loads and cadences on WAnT. Löllgen et al.[11] showed that blood lactate produced as a result of enhancing glycolytic metabolism was higher in work-matched cycling exercise with low-load / high cadence (100 rpm) than in that with high-load / low cadence (40 rpm, 60 rpm, and 80 rpm) at 100% $\dot{V}O_{2max}$. Glycolytic contribution (56%) was higher than ATP PCr (28%) or aerobic contribution (16%) during WAnT[12]. Hence, it is speculated that work-matched HIICT with low-load / high cadence can improve WAnT performance more than work-matched HIICT with high-load / low cadence.

Work-matched HIICT with high-load / low cadence may shorten time to reach peak power compared to HIICT with low-load / high cadence. Bieuzen et al.[13] reported that peak torque during work-matched cycling exercise with high-load / 50 rpm was observed in an earlier phase of the crank cycle (small crank angle when top-dead center is at 0°) than it was during low-load / high cadence conditions (87-93 and 110 rpm). Hence, work-matched HIICT with high-load / low cadence could possibly shorten the time to reach peak power than with low-load / high cadence. However, the effect of work-matched HIICT with different combinations of loads and cadences on time to reach peak power is not clear.

So, this study aims to investigate the effects of work-matched HIICT with different loads and cadences on WAnT performance.

Materials and Methods

Participants. Nineteen male university athletes initially participated in this study. However, three subjects could not complete the training due to injuries not associated with the experiments. Thus, data from the sixteen remaining subjects were used in the analysis. They had exercise habits of more than twice per week and belonged to the volleyball team (n = 7), soft tennis team (n = 3), soccer team (n = 3), ultimate team (n = 2) and badminton team (n = 1). Also, none of the subjects performed resistance training for the lower body more than two times per week in the past six months nor had cycling training for a competitive race. All subjects were informed of the potential risks of the experiment and gave their written consent to participate before the experiment. This study was approved by the Ethics Committee of the Faculty of Education at Hokkaido University (Approval Number: 17-24).

Experimental design. Subjects were divided into two experimental groups depending on their HIICT work volume based on their $\dot{V}O_{2peak}$ at pre-training. One group performed HIICT with high-load / 60 rpm (HL60, n = 8, mean ± SD; age: 20.3 ± 0.7 years, height: 175.0 ± 5.0 cm, body mass: 65.3 ± 4.1 kg) while the other group performed HIICT with low-load / 120 rpm (LL120, n = 8, mean ± SD; age: 19.9 ± 1.0 years, height: 173.6 ± 5.5 cm, body mass: 64.8 ± 6.7 kg). Both groups carried out HIICT in 18 sessions, at least twice per week over a 6-week period to avoid bias in the number of sessions per week. The work volume was gradually increased by 2.5% every 3 sessions in both groups. All sessions were supervised by expert investigators. We set 2 measurement days (Day 1 for $\dot{V}O_{2peak}$, Day 2 for WAnT). Measurement of $\dot{V}O_{2peak}$ was also performed after 9 training sessions (Inter).

High Intensity Intermittent Cycling Training (HIICT). Throughout the training period, HIICT was carried out using a cycle ergometer (Powermax-VII; Combi Wellness, Tokyo, Japan) after a warm-up cycling exercise with 90W for 10 minutes. The average value (mean ± SD) of relative intensity of warm-up (90W) to $\dot{V}O_{2peak}$ used in this study was 41.1 ± 4.8% $\dot{V}O_{2peak}$ in the HL60 and 41.4 ± 4.4% $\dot{V}O_{2peak}$ in the LL120. It is considered that warm up performed <60% $\dot{V}O_{2max}$ for 10-20 minutes improved short-term performance[14] because muscle temperature rises rapidly within 3-5 min and reaches a plateau after 10-20 min of exercise[15] and cause minimal creatine phosphate depletion[16]. Therefore, the warm-up performed in this study was considered appropriate. HIICT intensity started at 135% of $\dot{V}O_{2peak}$ (estimated by extrapolation methods using the relationship between work rate and oxygen uptake during an incremental exercise test using 60 rpm) and decreased by 5% every two sets. It consisted of eight sets of 20-s pedaling with 10-s passive rest between each set. Subjects were instructed to maintain either 60 rpm or 120 rpm and cadence was controlled using the display and a metronome. This HIICT protocol was based on a previous study[9].

The loads of the HL60 and LL120 were calculated based on the $\dot{V}O_2$ of the incremental exercise test conducted at 60 rpm to equalize the total work volume and time required for training in both groups. Deakin et al.[17] reported that the incremental exercise test protocol with gradual cadence at constant load (2.75 W per kg body mass) had a significantly lower maximal work load than did the incremental exercise test protocol with gradual load at constant cadence (90 rpm). Thus, it might be possible that maximal work load was significantly lower in the LL120 than was it in the HL60 if both groups performed the incremental exercise test using cadence of each training protocol (60 rpm or 120 rpm). In addition, if the relative load was calculated after observing a significant difference in maximal work load of the incremental exercise test, it might be also possible that the total work volume in the LL120 throughout the training period was significantly lower compared to the HL60. On the other hand, if the total work volume equalized after observing a significant difference in the maximal work load of the incremental exercise test, it would have been possible that the LL120 required a longer time of HIICT compared to the HL60. Therefore, because both groups perform HIICT with equal total work volume and time, the loads of HL60 and LL120 were calculated based on the $\dot{V}O_2$ of the incremental exercise test performed at 60 rpm. The absolute work rate (W) for performing HIICT was also calculated using the regression equation calculated from the work rate (W) and the peak value of $\dot{V}O_2$ at each stage during the incremental exercise test. Afterwards, the absolute load (kp) for performing HIICT was calculated by dividing the work rate (W) by 60 or 120. The average value (mean ± SD) of the absolute work loads of HIICT of each group throughout training period is in Table 1.

The total work volume during each session was calculated as sum of work volume of each set (actual work rate × 20-s) and total work volume (KJ) throughout 18 sessions was calculated as sum of work volume of each session. Based on a previous study, a cadence is considered insufficient if the work-volume for the 6-week period did not reach 90% of the work volume calculated before the experiment and was therefore excluded from the analysis[9].

Aerobic capacity. Based on methods applied in previous studies, the incremental exercise test was carried out to determine $\dot{V}O_{2peak}$ and HIICT intensity using a cycle ergometer (Powermax-VII; Combi Wellness, Tokyo, Japan)[9]. The test started at 60W and increased by 30W every 3 minutes until the subject could no longer maintain 60 rpm. Cadence during the test was controlled using a metronome and the display. Oxygen uptake was measured every 10-sec (10-s) using mixing chamber methods with a respiratory gas analyzer (VO2000; S&ME Inc., Tokyo, Japan) during the test, and the peak value was defined as $\dot{V}O_{2peak}$. In addition, time to exhaustion (TTE) during the incremental exercise test was measured as aerobic work capacity.

Wingate anaerobic test (WAnT) performance. After a warm-up cycling exercise with 90W for 10 minutes and dynamic stretching, WAnT was performed using a cycle ergometer (Powermax-VII; Combi Wellness, Tokyo, Japan) where they pedaled at maximum effort for 30 s. The load used was 7.5% of the body mass of each subject. The average value of absolute load (value were mean ± SD) were Pre and Post 4.9 ± 0.3 kp in the HL60, Pre and Post 4.9 ± 0.5 kp in the LL120. Peak power, peak rpm, average power, and time to reach peak power during the WAnT were used for analysis.

Statistical analyses. SPSS Statistics (Version 24.0 for Windows; SPSS Inc., Chicago, Ill., USA) was used for data analysis. Total work volume, achievement rate, percent change, and baseline difference between the groups were analyzed using unpaired t-test. $\dot{V}O_{2peak}$, TTE, and WAnT performance were analyzed using two-way (group x time) mixed-design ANOVA (within-subject factor: time; between-subject factor: group). A post hoc analysis was performed using the Bonferroni test. Data of total work volume, achievement rate, $\dot{V}O_{2peak}$, TTE and WAnT

Table 1. Mean absolute loads (kp) of high-intensity intermittent cycling training (HIICT) of each group.

Groups	Session	1-2 sets	3-4 sets	5-6 sets	7-8 sets
HL60	1-3 sessions	6.1 ± 0.3	5.9 ± 0.3	5.6 ± 0.3	5.4 ± 0.3
	4-6 sessions	6.2 ± 0.3	6.0 ± 0.3	5.7 ± 0.3	5.5 ± 0.3
	7-9 sessions	6.4 ± 0.3	6.1 ± 0.3	5.9 ± 0.3	5.6 ± 0.3
	10-12 sessions	6.6 ± 0.4	6.3 ± 0.3	6.0 ± 0.3	5.8 ± 0.3
	13-15 sessions	6.7 ± 0.4	6.5 ± 0.4	6.2 ± 0.3	5.9 ± 0.3
	16-18 sessions	6.9 ± 0.4	6.6 ± 0.4	6.3 ± 0.4	6.1 ± 0.4
LL120	1-3 sessions	3.1 ± 0.2	3.0 ± 0.2	2.8 ± 0.2	2.7 ± 0.2
	4-6 sessions	3.2 ± 0.2	3.0 ± 0.2	2.9 ± 0.2	2.8 ± 0.2
	7-9 sessions	3.2 ± 0.3	3.1 ± 0.2	3.0 ± 0.2	2.9 ± 0.2
	10-12 sessions	3.3 ± 0.2	3.2 ± 0.2	3.1 ± 0.2	2.9 ± 0.2
	13-15 sessions	3.4 ± 0.2	3.3 ± 0.2	3.1 ± 0.2	3.0 ± 0.2
	16-18 sessions	3.5 ± 0.2	3.3 ± 0.3	3.2 ± 0.2	3.1 ± 0.2

Values are expressed as mean ± SD.

performance are expressed as mean ± standard error (SE) and statistical significance level was set at $p < 0.05$. As indices of effect size, Cohen's d was used for unpaired t-test and post hoc comparisons while partial η^2 was used for ANOVA.

Results

Data did not show a significant difference between HL60 and LL120 at baseline ($\dot{V}O_{2peak}$: p = 0.856, Cohen's d = 0.093; TTE: p = 0.773, Cohen's d = 0.147; peak power during WAnT: p = 0.84, Cohen's d = 0.103; peak rpm during WAnT: p = 0.776, Cohen's d = 0.145; average power during WAnT: p = 0.875, Cohen's d = 0.08; time to reach peak power during the WAnT: p = 0.225, Cohen's d = 0.635). All 16 subjects who completed the 18 training sessions exceeded 90% achievement rate of the work volume calculated before the 6-week training period.

There was no significant difference in the total work volume and achievement rate throughout the training period between the two groups (Table 2).

Fig. 1 A-B shows the comparisons of changes in $\dot{V}O_{2peak}$ and TTE during incremental exercise test. Main effect of time was observed in $\dot{V}O_{2peak}$ ($p < 0.01$, partial $\eta^2 = 0.316$). However, interaction and main effect of group were not observed (interaction: p = 0.768, partial $\eta^2 = 0.019$; main effect of group: p = 0.704, partial $\eta^2 = 0.011$) (Fig. 1A). Main effect of time was observed in TTE ($p < 0.01$, partial $\eta^2 = 0.632$). However, interaction and main effect of group were not observed (interaction: p = 0.651, partial $\eta^2 = 0.03$; main effect of group: p = 0.565, partial $\eta^2 = 0.024$) (Fig. 1B).

Fig. 2 A-C shows the comparisons of changes in peak power, peak rpm, and average power during the WAnT of each group. Main effect of time was observed in peak power (p = 0.029, partial $\eta^2 = 0.298$), peak rpm (p = 0.037, partial $\eta^2 = 0.275$), and average power ($p < 0.01$, partial $\eta^2 = 0.446$) during WAnT. However, interaction (peak power: p = 0.416, partial $\eta^2 = 0.048$; peak rpm: p = 0.192, partial $\eta^2 = 0.118$; average power: p = 0.539, partial η^2 =

Table 2. Comparison of the total work volume and achievement rate throughout the training period between HL60 and LL120.

	HL60	LL120	p value	Cohen's d
Total work volume (KJ)	1025.6 ± 20.2	1033.9 ± 25.4	0.803	0.127
Achievement rate (%)	97.6 ± 0.5	97.4 ± 0.5	0.815	0.143

Values are expressed as mean ± SE.

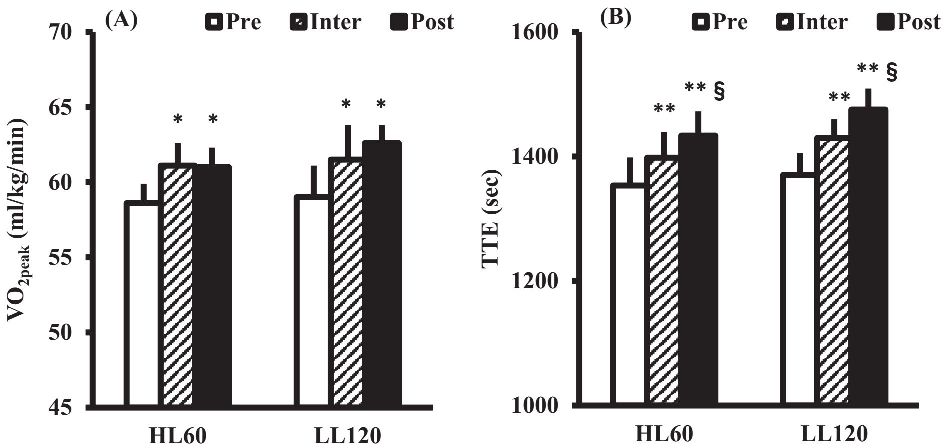

Fig. 1 Comparison of changes in (A) $\dot{V}O_{2peak}$, (B) time to exhaustion (TTE) between HL60 and LL120 during incremental exercise test.
Values are expressed as mean ± SE.
* $p < 0.05$ vs. Pre, ** $p < 0.01$ vs. Pre, § $p < 0.01$ vs. Inter

0.027) and main effect of group (peak power: $p = 0.623$, partial $\eta^2 = 0.018$; peak rpm: $p = 0.477$, partial $\eta^2 = 0.037$; average power: $p = 0.994$, partial $\eta^2 = 0.000$) were not observed.

Fig. 2D shows the comparison of change in time to reach peak power during the WAnT of each group. Interaction was observed ($p = 0.024$, partial $\eta^2 = 0.315$). In the post-hoc analysis, time to reach peak power was significantly shortened in only HL60 from pre- to post-training ($p < 0.01$, Cohen's $d = 0.713$). In addition, shortening rate of time to reach peak power during WAnT was significantly higher in HL60 than in LL120 ($p < 0.01$, Cohen's $d = 1.647$, Fig. not shown).

Discussion

We examined the effects of work-matched HIICT with different loads and cadences on WAnT performance. After the 6-week HIICT, peak power, peak rpm, and average power during WAnT increased in both HL60 and LL120 groups. Time to reach peak power during WAnT significantly shortened only in HL60 group from pre- to post-training.

The results of $\dot{V}O_{2peak}$ in this study support the results of a previous study that used similar HIICT protocols[9]. There are two possible reasons for these results. First, the total work volume throughout the training period may have had an effect on the results of $\dot{V}O_{2peak}$. Total work volume is a training variable that influences mitochondrial content, which is related to oxygen utilization[18]. In this study, the total work volume throughout the training period was not significantly different between the HL60 and LL120 groups (Table. 2). Therefore, it is speculated that a similar increase of $\dot{V}O_{2peak}$ in HL60 and LL120 was brought about by improvements in oxygen utilization due to similar increases in mitochondrial content. Second, it might be possible that cardiac output was equally improved in the HL60 and LL120 groups. Gotshall et al.[19] showed that submaximal cycling exercise at equal power output (approximately 62.5% power output$_{max}$) with 110 rpm increased cardiac output more than in other cadence conditions (70 rpm and 90 rpm). On the other hand, it has been reported that cardiac output during incremental cycling exercise also increased parallel with exercise intensity[20]. The HIICT in this study used the supramaximal intensity and had a higher relative intensity than in a previous study by Gotshall et al.[19]. Thus, $\dot{V}O_{2peak}$ may be equally improved by increasing cardiac output

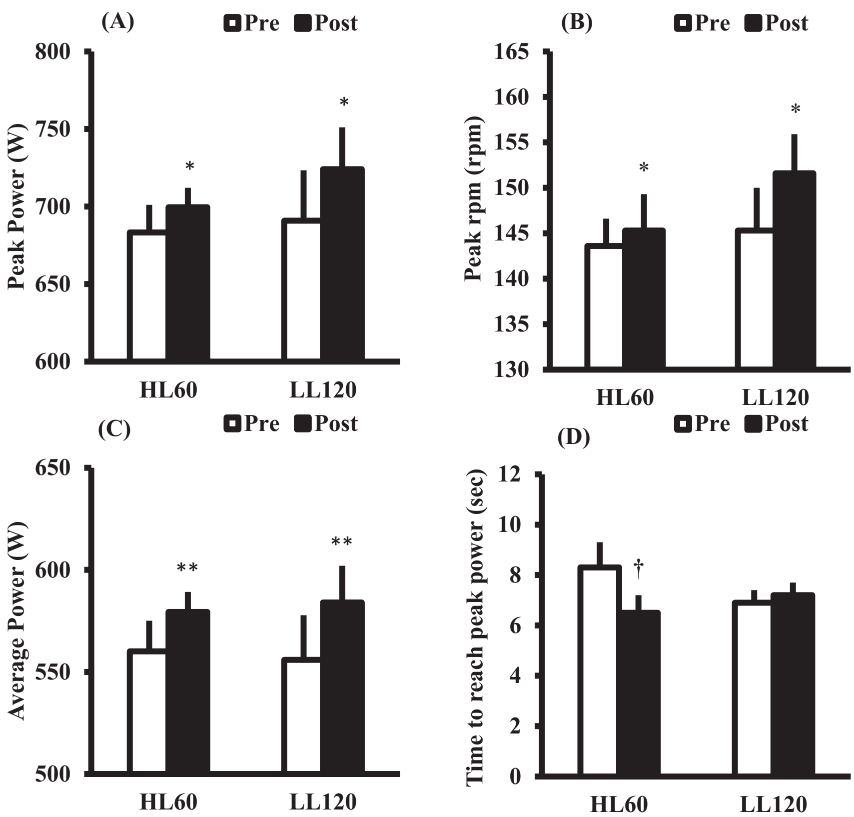

Fig. 2 Comparison of changes in (A) peak power, (B) peak rpm, (C) average power, and (D) time to reach peak power between HL60 and LL120 during Wingate anaerobic test.
Values are expressed as mean ± SE.
* $p < 0.05$ vs. Pre, ** $p < 0.01$ vs. Pre, † $p < 0.01$ vs. HL60 Pre

by the same rate in HL60 and LL120. In future studies, acute $\dot{V}O_2$ response during HL60 and LL120 should be investigated.

In this study, peak power and peak rpm during WAnT were equally improved in HL60 and LL120. There are two possible reasons for this. First, it is possible that the different contributions of knee extension and hip extension power during HIICT of each group affected results of peak power during WAnT. Positive work during cycling exercise was mainly produced by knee extensors and hip extensors[21]. However, as the load during cycling exercise increases, the relative contribution of knee extension power decreases, while the relative contribution of hip extension power increases[22]. On the other hand, as the cadence during work-matched cycling exercise increases, the knee extension power increases while hip extension power decreases[23,24]. Therefore, it is speculated that the peak power of both groups equally improved due to improvement in the hip extension power of HL60 and in the knee extension power of LL120. Second, it might be possible that cadences during HIICT affected the results of peak rpm during WAnT. In a previous study, Tabata et al.[25] indicated that 50 rpm during cycling exercise corresponded to angular velocity of about $140°\cdot s^{-1}$. In addition, HIICT with 50 rpm (5 times per week for 7 weeks) improved the isokinetic knee extension power at a slower angular velocity (30°, 60°and $120°\cdot s^{-1}$) than $140°\cdot s^{-1}$, but did not lead to an improvement in isokinetic knee extension power at a faster angular velocity (180°, 240° and $300°\cdot s^{-1}$) than $140°\cdot s^{-1}$. Thus, it was considered that peak rpm during WAnT was equally improved in HL60 and LL120 due to cadences during both HL60 and LL120 that were lower than peak rpm during WAnT and neither group had an advantage of cadence (Fig. 2B).

Contrary to our hypothesis, the average power during WAnT improved in both HL60 and LL120, with no significant difference. Based on this result, it is suggested that glycolytic capacity was similarly improved in both HL60 and LL120. Löllgen et al.[11] showed that blood lactate produced as a result of enhancing glycolytic metabolism is higher in high-intensity cycling exercise with low-load / high cadence (100 rpm) than with high-load / low cadence (40 rpm, 60 rpm and, 80 rpm) at 100% $\dot{V}O_{2max}$. On the other hand, Deakin et al.[17] reported that there were no significant differences in post-exercise blood lactate between the incremental exercise test protocol with gradual cadence at constant load (2.75 W per kg body mass) and the incremental exercise test protocol with gradual load at constant cadence (90 rpm). Deakin et al.[17] indicated that cycling exercise with high-load / low cadence and low-load / high cadence at near or maximal effort equally enhance glycolytic metabolism. We used a higher exercise intensity than in a previous study by Löllgen et al.[11]. In addition, the glycolytic contribution was higher than ATP PCr or aerobic contribution during WAnT[12]. Therefore, it is possible that the average power during WAnT equally improved in HL60 and LL120 due to a similar improvement in glycolytic capacity in these two groups.

The time to reach peak power during WAnT was shortened only in HL60, and this supports our hypothesis. Bieuzen et al.[13] reported that peak torque during work-matched cycling exercise with high-load / 50 rpm was observed in an earlier phase of the crank cycle than it was during low-load / high cadence conditions (87-93 and 110 rpm). In addition, Häkkinen et al.[26] reported that explosive jump training induces improvements in fast force production by activating more motor units during an early phase after the onset of muscle contraction. Thus, the time to reach peak power during WAnT might be shortened only in HL60 because more motor units were activated during an early phase after the onset of HIICT due to the higher load in HL60 compared to LL120.

In this study, the work load (kp) of HIICT was calculated based on the $\dot{V}O_{2peak}$ value at pre-training. However, this is not practical and is not accessible for most athletes because measurement of $\dot{V}O_{2peak}$ requires expensive equipment and experts. To calculate the work load for HIICT, it is possible to use a relative value of each subject's body mass. In this study, the average value (mean ± SD) of work load of HL60 was 8.2 ± 0.3% - 10.7 ± 0.5% of body mass. Therefore, it is expected that the same effects as HL60 can be obtained by using a work load of 8-11% of body mass for male adult athletes with relatively high $\dot{V}O_{2max}$ or $\dot{V}O_{2peak}$.

There were two limitations in this study. First, although the external work load (total work volume) equalized, the internal work load (oxygen demand) did not equalize. Second, there was also a limitation in calculating the supramaximal exercise intensity using the relationship between exercise intensity (work rate) and oxygen uptake during the incremental exercise test. Tabata[27] does not recommend calculating supramaximal exercise intensity using the relationship between exercise intensity and oxygen uptake during the incremental exercise test because it takes longer time for $\dot{V}O_2$ to reach the steady state at high-intensity exercise than low-intensity exercise. In addition, $\dot{V}O_2$ does not reach a steady state and slowly developing increase during exercise above the lactate threshold[28]. Based on these findings, although it was not confirmed whether the $\dot{V}O_2$ reached a steady state at each stage during incremental exercise in this study, it is possible that $\dot{V}O_2$ did not reach a steady state at the late stage during the incremental exercise test. Therefore, it is considered that calculating the supramaximal exercise intensity using the relationship between exercise intensity and oxygen uptake during the incremental exercise test was a limitation of this study.

Conclusions

We investigated the effects of work-matched high-intensity intermittent cycling training with different loads and cadences on WAnT performance. After the 6-week HIICT, peak power, peak rpm, and average power during WAnT and $\dot{V}O_{2peak}$ increased in both the HL60 and LL120 groups. The time to reach peak power was significantly shortened only in the HL60 group from pre- to post-training. These results suggest the effectiveness of work-matched HIICT with high-load / low cadence on WAnT performance. In future studies, acute physiological responses to work-matched HIICT with different combinations of loads and cadences should be investigated.

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Conflict of Interests

All authors declare no conflict of interests.

Author Contributions

NT, KT, KS, MM conceived and designed the study. NT performed the study. NT analyzed the data. NT wrote the paper. All authors critically reviewed, revised and approved the manuscript.

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