ORIGINAL ARTICLE

Heart rate variability-guided aerobic training without moderate-intensity enhances submaximal and maximal aerobic power with less training load

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ABSTRACT

This study aims to clarify the effects of heart rate variability (HRV)-guided aerobic training on submaximal and maximal aerobic power. Twelve active men participated in a 5-week intervention and were divided into two groups: a block periodization training group (BP, n = 6) and a HRV-guided training group (HRV-G, n = 6). All participants underwent the same aerobic training during week one. In weeks 2–5, the training load for the HRV-G was adjusted based on the HRV of an individual on waking. The BP underwent 2 weeks of overload training followed by 2 weeks of taper training. To determine the submaximal and maximal aerobic powers, an incremental load test was performed at baseline and once a week. The internal load during the training sessions was derived from the heart rate. The monotony and strain were calculated from the internal load. TRIMP and the strain were lower in the HRV-G than BP. The HRV-G had a greater relative distribution of time spent at low-intensity and a lower relative distribution of time spent at high-intensity than BP. The change in the maximal and submaximal aerobic power was greater in the HRV than in BP. The current findings indicate that combined low- and high-intensity HRV-guided training enhance increases the submaximal and maximal aerobic power, regardless lower training load than BP.
Keywords: Sport medicine, Cardiac-autonomic nervous system, Aerobic training, Periodization, Training adaptation.

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INTRODUCTION

Aerobic training increases submaximal and maximal aerobic power, and its effect on aerobic power depends on the intensity, frequency, and duration of the prescribed exercises (Wenger & Bell, 1986). A aerobic training program is generally supervised and predetermined. Block periodization (BP) is a popular method for optimizing maximal aerobic power by focusing on a targeted ability for a given period of time (Issurin, 2010). One aspect of BP is tapering following overload, which has been shown to increase maximal aerobic power (Thomas & Busso, 2005). There is an interindividual variation in the change in aerobic power, even when the relative training load is the same. In fact, 5% of all participants exhibit little or no effect, while another 5% show an increase in effect by 40–50% (Skinner et al., 2001). Aubry et al. (2014) (Aubry et al., 2014) also revealed that individuals who responded better to a 3-week overload training exhibited greater gains in maximal aerobic power after a 2-week tapering period compared to those who responded less or did not respond to the overload training. A magnitude of aerobic adaptation is influenced by internal load from heart rate than external load (MORINAGA & TAKAI, 2024; Taylor et al., 2018). Therefore, it is necessary to focus on internal load and design an aerobic training program that reduces individual variations in adaptation to aerobic training.

Heart rate variability (HRV) derived from R-R intervals (RRi) such as the high-frequency domain (HF), root mean squared differences of successive RRi transformed by natural logarithm (LnRMSSD), and coefficients of covariance in LnRMSSD ($CV_{LnRMSSD}$) can be a valid and reliable tool for assessing the cardiac-autonomic regulation of parasympathetic activity (Camm et al., 1996). Changes in parasympathetic activity indices may reflect positive or negative adaptations to aerobic training (Buchheit et al., 2010; Da Silva et al., 2014; Hautala et al., 2003; Le Meur et al., 2013; Nummela et al., 2009; Plews et al., 2012). Da Silva et al. (2014) (Da Silva et al., 2014) demonstrated a positive relationship between increases in LnRMSSD and increases in 5-km running time after a 7-week endurance training intervention (6 days per week) in trained endurance runners. After 3 weeks of overload training for trained triathletes, the LnRMSSD value attenuates with decreasing running distance until exhaustion (Le Meur et al., 2013). Furthermore, 7 weeks of aerobic training simultaneously reduces $CV_{LnRMSSD}$ and increases the distance of the Yo-Yo intermittent recovery test level 1 (Boullosa et al., 2013). Hautala et al. (2003) (Hautala et al., 2003) demonstrated that the magnitude of individual cardiac parasympathetic activity is associated with changes in the maximal oxygen uptake and independent of the training volume. Considering the earlier studies, a potential factor for interindividual variation in aerobic adaptation is the adjustment of the automatic cardiovascular regulation of parasympathetic activity (Hautala et al., 2003). However, the relationship between the changes in HRV and aerobic performance gain remains unclear.

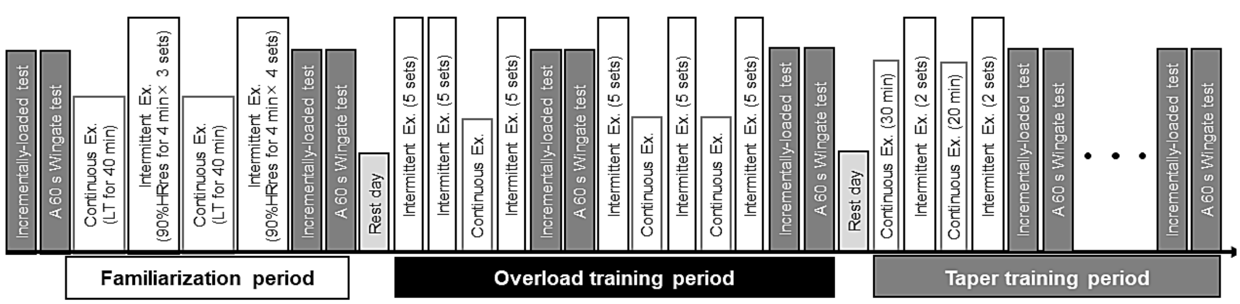
Based on the above studies, it has been recommended that individualized aerobic training guided by HRV, in which the training load is adjusted by monitoring the daily HRV of the individual, may be more effective than predetermined aerobic training for improving maximal oxygen uptake and aerobic power (Javaloyes et al., 2019; Kiviniemi et al., 2010; Kiviniemi et al., 2007; Vesterinen et al., 2016). Compared to predetermined aerobic training, HRV-guided training reduces the number of moderate- and high-intensity training sessions (Carrasco-Poyatos et al., 2022; Vesterinen et al., 2016) and the proportion of moderate intensity training (Javaloyes et al., 2019). Daily variation in LnRMSSD is also lower with HRV-guided training than with predetermined aerobic training (Javaloyes et al., 2019). Regarding aerobic power, HRV-guided training produces greater increases in aerobic peak power and power at moderate and high intensities than predetermined training (Javaloyes et al., 2019). Furthermore, HRV-guided training is as effective as or more effective at maximizing aerobic power than the BP strategy (Javaloyes et al., 2020; Nuuttila et al., 2017). For example, Javaloyes et al. (2020) (Javaloyes et al., 2020) demonstrated that training-induced changes in the maximal aerobic power and submaximal power output at first ventilatory threshold were greater with HRV-guided training compared to BP training.

Exercise beyond the lactate threshold (LT) intensity facilitates sympathetic nerve activity and delays fatigue recovery (Seiler, 2010). Therefore, aerobic training programs for endurance athletes should consist of exercises that combine an intensity below the LT with an intensity above the onset of blood lactate accumulation (OBLA) (polarized training) (Stöggl & Sperlich, 2015). Furthermore, Esteve-Lanao et al. (2007) (Esteve-Lanao et al., 2007) divided sub-elite runners into two groups: one consisting of a higher volume of low-intensity training and the other consisting of less low-intensity training and moderate-intensity training and found that the first group timed better in a 10.4-km cross-country than the second group. The HRV-guided training program in the earlier study included moderate-intensity training, which may have reduced the effect on maximal and submaximal aerobic power. This study tested the hypothesis that the HRV-guided aerobic training, consisting of low- and high-intensity, enhanced maximal and submaximal aerobic power adaptation compared to BP training programs, regardless of the training load.

METHODS

Participants

Twelve active men (20.4 ± 1.8 years, 177.9 ± 4.4 cm, 73.4 ± 7.1 kg) were divided into two groups: a BP training group (BP, n = 6) and a HRV-guided training group (HRV-G, n = 6). The performance level of all subjects, as classified by training time and frequency and maximal aerobic power, were levels 2 (De Pauw et al. 2013). The participants had been running for 1 to 2 h, at least five times a week for over five years. None of the participants reported any illness or were prescribed medications for cardiovascular, metabolic, or orthopaedic disorders. We explained the purpose and methods of the study in detail and obtained informed consent from the participants before they participated in the experiment. This study was approved by the National Institute of Fitness and Sports in Kanoya (No. 11-101).



Note. Ex, exercise; HRres, heart rate reserve.

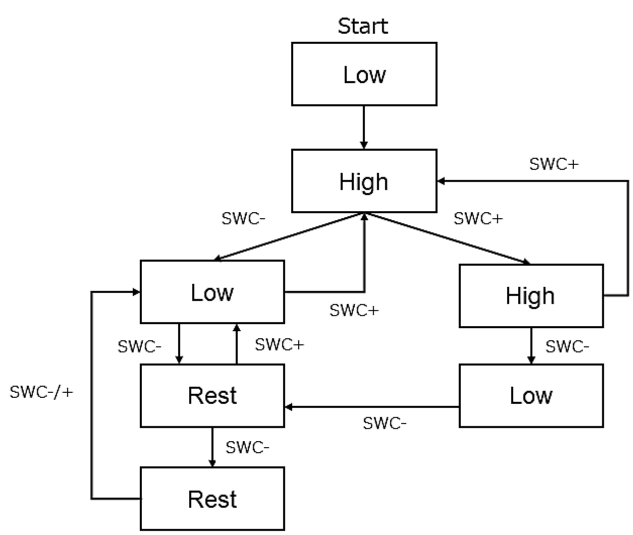
Figure 1. Training program in experimental and control groups for familiarization and experimental period referenced by Morinaga and Takai (2023, in press).

Experimental design

According to the training modality reported by Morinaga and Takai (2023) (MORINAGA & TAKAI, 2024), the BP group participated in a 5-week aerobic training intervention (Figure 1). Two protocols of aerobic training were prescribed using a bicycle ergometer (Aerobic 75XⅢ, COMBI, Japan). One included low-intensity aerobic training of 40 min of continuous exercise at the intensity of LT, and the other included high-intensity aerobic training with 4 min × 4 sets of high-intensity intermittent exercise at an intensity of 90% of the heart rate reserve (HR_{res}, HR_{res} = (HR in a training session – HR at rest)/(maximal HR – HR at rest)) with a 3-min active recovery period at an intensity of 50%HR_{res}. The heart rate was measured during the prescribed training to determine the internal load of training sessions. During the first week (familiarization period), all the participants performed an identical aerobic training program to familiarize themselves with the exercises. The experimental period was set to four weeks, corresponding to the period between 2nd to 5th week. For BP, during the period from 2nd to 3rd week, the training duration was increased such that the external load increased by 40% compared to that of the familiarization period (Le Meur et al., 2013), which was we expected to induce above moderate intensity (Halson et al., 2002). During weeks 4 and 5, the external load was decreased by 50% by shortening the training duration compared to the familiarization period (Bosquet et al., 2007). For HRV-G, the participants were prescribed low- or high-intensity training based on individual HRV scores measured upon awakening. To adjust for the training intensity, an incremental load test was conducted at baseline and once a week.

HRV-guided training

All participants had their HRV measured as prescribed below, from a week before to the end of the intervention. Participants recorded their RRi using HRV analysis software (MCsoftware, Hosanad, Italia). RRi was recorded every morning immediately after waking up and emptying the bladder. Participants were in the supine position for 5 min. The obtained data were log-transformed to reduce bias due to non-uniformity of the error (LnRMSSD). After performing a 7-day moving average of the daily $LnRMSSD_{7d}$ (Plews et al. 2012) values, we calculated the weakly mean ($LnRMSSD_{7d}$) and coefficient of variance in LnRMSSD ($CV_{LnRMSSD7d}$). From power spectral analysis, components in the frequency band from 0.03 to 0.15 Hz were considered low frequency (LF), and those in the range of 0.15 to 0.4 Hz were considered high frequency (HF). The use of normalized units {HF or LF components / (the total power – very LF component) × 100} is crucial to obtain values for the autonomic cardiac modulation, because the high interindividual variation in RRi total variance and direct current noise (Manzi et al., 2009) and computed as the ratio of LFnu and HFnu (LF/HF). All HRV parameters were calculated for the familiarization period and weekly during the experimental period.



Note. When $LnRMSSD_{rollave}$ remained inside SWC (+), high-intensity interval training sessions was prescribed. If $LnRMSSD_{rollave}$ fell outside SWC (-), low intensity or rest were described. $LnRMSSD_{rollave}$, 7-day moving average of the natural logarithm of the root-mean squared differences of successive RR intervals; SWC, smallest worthwhile change. Low: continuous pedalling exercise; High, high intermittent interval pedalling exercise.

Figure 2. Heart Rate Variability-guided training decision-making schema. Modified from Vesterinen et al., 2019.

To detect the variability of $LnRMSSD_{7d}$ to the prescribed training, the smallest worthwhile change (SWC) was derived from the mean and standard deviation (SD) of LnRMSSD in the familiarization period {mean ± 0.5 × SD} for each participant (Vesterinen et al., 2016). For HRV-G, the morning value of $LnRMSSD_{7d}$ was used to prescribe the training to be performed in a given training session. This procedure is illustrated in Figure 2. For example, if the $LnRMSSD_{7d}$ was within the SWC, the participant continued to perform high-intensity intermittent exercise. If the $LnRMSSD_{7d}$ value deviated from the SWC, the participant performed low-intensity exercise or took a day off.

Incremental load test

The participants performed an incremental load test on a bicycle ergometer (Aerobike 75XL III, COMBI, Japan), and the results were used to quantify their maximal aerobic power (W_{max}), power at LT (W_{LT}), and power at OBLA (W_{OBLA}) (Manzi et al., 2009). The participants adjusted the handlebar and saddle heights of the ergometer before the test, followed by a 5-min standardized warm-up, in which they pedalled the bicycle with an initial load of 50 W. The load was increased by 25 W every 3 min until exhaustion. The pedalling frequency was held constant at 70 rpm using an audible metronome. The heart rate was measured using a telemetric sensor (RC3 GPS, Polar, Finland). Blood lactate concentration (Bla) was measured from the fingertip using a blood lactate meter (Lactate Pro2, Arkray, Japan) 30 s before the end of each stage. The Bla level measured at the stage when exhaustion was reached was defined as the maximal Bla (Bla_{max}). We also assessed the rate of perceived exertion (RPE) using the Borg scale (6–20 points) (Borg, 1973) at the end of each stage. We calculated the maximal aerobic power (W_{max}) using the following equation based on the method proposed by Halson et al. (2002) (Halson et al., 2002).

$$W_{max} = W_{final} + \left(\frac{t}{180}\right) \times 25$$

Here, W_{max} is the maximal aerobic power (W); W_{final} is the pedalling power of the final stage (W); *t* denotes the time at the incomplete stage (s); the exercise time at each stage is 180 s; and the incremental load is 25 W. We computed the maximal heart rate (HR_{max}) after calculating the moving average of the time-series data for 30 s. We defined W_{LT} and W_{OBLA} as the pedalling power at 2 and 4 $mmol \cdot l^{-1}$, respectively, which were derived from the relationship between Bla and the pedalling power in the incremental load test ($y = a \cdot e^{bx}$) (Manzi et al., 2009). The aerobic power was normalized to body mass ($W \cdot kg^{-1}$).

Sixty-second Wingate test

The participants pedalled with maximal effort for 60 s on an electrical brake bike (POWER MAX VⅢ, KONAMI, Japan), with a load set at 7.5% of the body mass of the participant (Vandewalle et al., 1987). Before the test, we adjusted the handlebars and saddle and fixed both feet to the pedals with non-elastic belts. The position of one pedal was measured using a potentiometer (AO-PMA2, Applied Office, Japan), and the analogue signal was amplified using an amplifier (DPM-912A, Kyowa, Japan) and recorded in a personal computer via an A/D converter (PowerLab 16/35, ADinstruments, Australia) at a sampling frequency of 100 Hz. The number of rotations (rpm) was calculated from the data obtained using an analysis software (Labchart 7, ADinstruments, Australia). We calculated the pedalling power (W) by multiplying the workload (kp) by the number of rotations {workload (kp) × number of rotations per minute (rpm) × 0.98 (constant)}. The mean power for 60 s (W_{60}) was calculated as the index of aerobic work capacity (Gastin, 2001) and normalized to body mass ($W \cdot kg^{-1}$).

Internal load

To quantify the training load in the training and test sessions, we calculated the training impulse (TRIMP) from the exercise HR_{res} and the weighting factor and training duration for each individual {training duration (min) × HR_{res} × weighting factor} (Manzi et al., 2009). The weighting factor was obtained from the regression equation ($y = a \cdot e^{bx}$) of the Bla–HR_{res} relationship in the incremental load test. Training intensity distributions were classified into three categories based on the HR_{res} at the LT and OBLA. As indices of the training load (Foster, 1998), the monotony and strain of the TRIMP were also calculated as the sum of the TRIMP, mean, and standard deviation weekly of the experimental period. The monotony was then calculated by dividing the mean by the standard deviation, and the strain was calculated by multiplying the sum of the TRIMP by the monotony.

Statistical analysis

All variables are presented as means and SDs. The independent variables are submaximal and maximal aerobic power, internal loads, and HRV parameters before (PRE) and after (POST) the experimental period. We calculated the relative changes in aerobic power using the following equation: (POST values – PRE values) / PRE values × 100. Additionally, to demonstrate the consistency of adaptations in aerobic power, the coefficient of variation (CV) for the rate of change in aerobic power between subjects was calculated.

All variables were analysed using the R software (version 4.4.0). To confirm the differences between groups at the PRE stage for all variables, Mann-Whiteny U test was conducted. Subsequently, the differences in internal loads between groups during the experimental period, Mann-Whiteny U test was performed. Given the non-normality and heteroscedasticity of the aerobic powers and HRV parameters, the Aligned Rank Transform (ART) was applied using the ARTool package (Wobbrock et al., 2011). This allowed for nonparametric ANOVA to be conducted on the data, which included group and time as independent variables. An ANOVA was then conducted to examine the main effects and interaction effects. When significant effects were detected, Bonferroni as *post hoc* comparisons were performed using the emmeans package to provide detailed pairwise comparison (Elkin et al., 2021). All significance was set at $p < .05$.

We evaluated the data using magnitude-based inference for practical significance (Hopkins et al. 2009). We used qualitative inference to assess differences in the independent variables between groups over time (Hopkins 2006). Standardized changes and 90% confidence limits (CL) were calculated as the following thresholds: ≤0.2 (*trivial*), >0.2 (*small*), >0.6 (*moderate*), >1.2 (*large*), >2.0 (*very large*), and >4.0 (*extremely large*). We rated the qualitative changes in the higher or lower independent variables as: <0.5% (*almost certainly not*), 0.5–5% (*very unlikely*), 5–25% (*unlikely*), 25–75% (*possible*), 75–95% (*likely*), 95–99.5% (*very likely*), and >99.5% (*most likely*). If the chance of a higher or lower difference is >5%, then the true difference is considered *unclear* (Hopkins et al. 2009).

RESULTS

A total of 12 subjects completed the whole study. No significant difference observed in the indices of internal load, submaximal and maximal aerobic power, and HRV parameters in PRE values.

Internal load for the intervention period

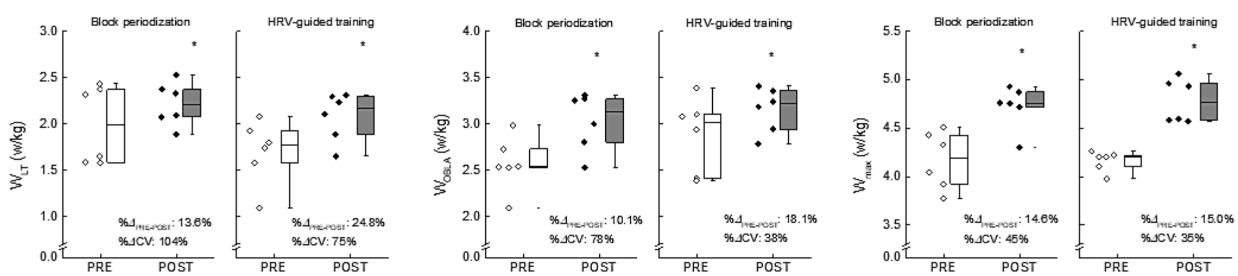
Table 1 presents the descriptive data on the internal load for the experimental period. Training duration was 486 min for BP and 465 ± 89 min for HRV-G. TRIMP was significantly lower in HRV-G ($p < .05$, ES = -1.54; *very likely*) than in BP. Strain was significantly lower in HRV-G than in BP ($p < .05$, ES = –1.70; *very likely*). Monotony was no group different between the groups ($p = .43$, ES = -0.62; *unclear*).

Table 1. Descriptive data on indices of training load for the experimental period.

	BP	HRV-G	ES	Qualitative inference
TRIMP (a.u.)	1472 ± 234	1015 ± 347*	-1.54	*very likely*
Monotoy (a.u.)	1.13 ± 0.09	1.02 ± 0.22	-0.62	*unclear*
Strain (a.u.)	1644 ± 161	1048 ± 470*	-1.70	*very likely*
Time spent at each intensity (min)				
<LT	128 ± 20	205 ± 85	1.29	*likely*
LT-OBLA	189 ± 35	174 ± 58	-0.30	*unclear*
>OBLA	169 ± 44	85 ± 59*	-1.61	*very likely*
Relative distribution of time spent at each intensity (%)				
<LT	26 ± 4	44 ± 19	1.33	*very likely*
LT-OBLA	39 ± 7	37 ± 9	-0.19	*unclear*
>OBLA	35 ± 9	18 ± 13	-1.45	*very likely*

*Note. The values are expressed as means and SDs. BP: block periodization training group; HRV-G: heart rate variability-guide training group. TRIMP: training impulse. *: significantly different compared to BP (p < .05).*

The time spent below the LT tends to be longer in HRV-G than in BP (p = .06, ES = 1.25; *likely*). The time spent above the OBLA was significantly shorter in the HRV-G than BP (p < .05, ES = -1.61; *very likely*), and the time spent in the intensity between the LT and OBLA was tend to shorter in HRV-G than in BP (p = .48, ES = -1.25; *likely*). In regard to the proportion of time spent in each intensity zone to training duration, the intensity below the LT was tend to greater in HRV-G than in BP (p = .09, ES = 1.33; *very likely*), and the intensity above the OBLA in HRV-G tend to lower than in the BP (p = .09, ES = -1.45, *very likely*). The proportion of the intensity between the LT and OBLA was no group different between the groups (p = .37, ES = 0.19; *unclear*).



Note. W_{max}: maximal aerobic power, W_{LT}: aerobic power at lactate threshold; W_{OBLA}: aerobic power at onset of blood lactate threshold. Blank circle: PRE-value; black circle: POST-value-a: significantly different compared to PRE.

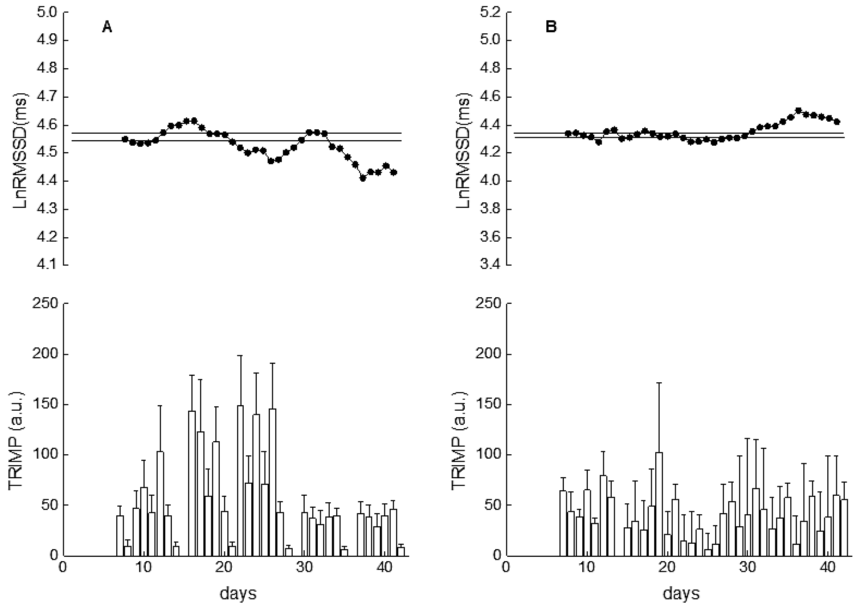
Figure 3. The submaximal and maximal aerobic power before and after experimental period.

Training-induced changes in maximal and submaximal aerobic power

For the experimental period, submaximal and maximal aerobic power significantly increased (Figure 3). Within-group degree of changes are in HRV-G (W_{LT}: 25 ± 19%, ES = 1.17, *likely*; W_{OBLA}: 18 ± 7%, ES = 1.50, *very likely*; W_{max}: 15 ± 5%, ES = 3.40, *most likely*), in BP (W_{LT}: 14 ± 14%, ES = 0.40, *unclear*; W_{OBLA}: 10 ± 8%, ES = 0.44, *unclear*; W_{max}: 14 ± 6%, ES = 2.04, *very likely*). Additionally, the coefficients of covariance in the relative changes in submaximal and maximal aerobic power was lower in HRV-G group than in BP group (W_{LT}: HRV-G vs. BP, 75% vs. 143%; W_{OBLA}: 38% vs. 121%; W_{max}: 35% vs. 49%).

Training-induced changes in the indices of parasympathetic activity

Figure 4 shows the longitudinal changes in TRIMP and LnRMSSD for each training group throughout the intervention, and Table 2 presents the descriptive data on the indices of cardiac-parasympathetic activity for the experimental period. No significant change in HRV parameters was found for the experimental period (p = .56 to .92, ES = 0.01 to 0.55, *unclear*). HFnu was significantly higher ($p < .05$, ES = 1.54, *very likely*) and LFnu and LF/HF were significantly lower ($p < .05$, ES = -1.59 to -1.89, *very likely*) in HRV-G than in BP for experimental period.



Note. The time course data are expressed as means of subjects each group. Black circle, 7-day moving average of LnRMSSD; blank bar: daily Training impulse; A: block periodization group, B: heart rate variability-guided training group.

Figure 4. Time course data on LnRMSSD and TRIMP throughout the intervention.

Table 2. Descriptive data on heart rate variability parameters for the intervention period.

	PRE	POST	ES	Qualitative inference
BP				
RRi (ms)	1140 ± 130	1125 ± 129	-0.46	*unclear*
LnRMSSD (ms)	4.56 ± 0.47	4.44 ± 0.44	-0.17	*unclear*
LnRMSSD/RRi (a.u.)×10^{-3}	4.02 ± 0.18	3.98 ± 0.25	-0.36	*unclear*
$CV_{LnRMSSD}$ (%)	1.66 ± 1.10	1.74 ± 1.12	-0.04	*unclear*
LFnu	66.4 ± 7.8	66.7 ± 9.8	0.04	*unclear*
HFnu	33.9 ± 7.8	33.7 ± 9.4	-0.02	*unclear*
LF/HF	2.42 ± 0.78	2.66 ± 0.79	0.31	*unclear*
HRV-G				
	PRE	POST	ES	Qualitative inference
RRi (ms)	1122 ± 141	1139 ± 144	0.08	*unclear*
LnRMSSD (ms)	4.43 ± 0.34	4.46 ± 0.38	0.18	*unclear*
LnRMSSD/RRi (a.u.)×10^{-3}	3.99 ± 0.23	3.98 ± 0.32	-0.26	*unclear*
$CV_{LnRMSSD}$ (%)	1.14 ± 0.35	0.94 ± 0.45	-0.50	*unclear*
LFnu	57.0 ± 10.7	51.1 ± 10.3	-0.56	*unclear**
HFnu	43.0 ± 10.7	48.9 ± 10.3	0.56	*unclear**
LF/HF	1.99 ± 1.01	1.37 ± 0.59	-0.43	*unclear**

*Note. Values are expressed as means and SDs. BP: block periodization training group; HRV-G: heart rate variability-guide training group. RRi: R-R interval; LnRMSSD: 7-day moving average of the root mean squared differences of successive RRi transformed by natural logarithm; LnRMSSD/RRi: ration LnRMSSD to RRi; CVLnRMSSD: coefficients of covariance in LnRMSSD. *: significantly main group different compared to BP (p < .05).*

DISCUSSION

The main findings obtained here were that the HRV-guided training increased the submaximal and maximal aerobic power to the same extent as BP even when strain was lower in HRV-guided training than in BP, and interindividual variation was lower in HRV-guided training than BP, and HRV-guided training enhanced cardiac-parasympathetic activity.

Comparison of the HRV-G training and the regular training in the training-induced changes in the maximal and submaximal aerobic power

In the HRV-G, the relative changes in submaximal and maximal aerobic power were 24.8% for W_{LT}, 18.1% for W_{OBLA}, and 15.0% for W_{max}. In the earlier studies, the relative changes in aerobic power induced by HRV-guided training ranged from 2.8 to 37.6% for aerobic power at the LT level (Javaloyes et al., 2019; Javaloyes et al., 2020; Nuuttila et al., 2017; Vesterinen et al., 2016), from 2.6 to 22.9% for aerobic power at the OBLA level (Javaloyes et al., 2019; Javaloyes et al., 2020; Nuuttila et al., 2017; Schmitt et al., 2018; Vesterinen et al., 2016), and from 5.1 to 10.4% for maximal aerobic power (Javaloyes et al., 2019; Javaloyes et al., 2020; Kiviniemi et al., 2010). The submaximal aerobic power obtained in this study was similar; however, the maximal aerobic power was greater than that reported in previous studies. The greater gain in the maximal aerobic power might be due to differences in the HRV-G prescription, training load, and initial LnRMSSD. Further, aerobic training which combines intensity below the LT with intensity above the OBLA is prescribed in this study. However, previous studies have designed training programs that include moderate intensity (Carrasco-Poyatos et al., 2022; Javaloyes et al., 2019; Javaloyes et al., 2020; Vesterinen et al., 2016). Esteve-Lanao et al. (2007) (Esteve-Lanao et al., 2007) found that for sub-elite runners, the gain in a 10.4-km run was greater in the training below the ventilation threshold (VT) 1 than in the training ranging from VT1 to VT2, when the amount of the training above VT2 was equal between groups. Neal et al. (2013) (Neal et al., 2013) showed that increases in the maximal aerobic power were significantly greater with polarized training combined with low- and high-intensity training than with low- and moderate-intensity training. Aerobic training above moderate intensity evokes sympathetic activity (Chwalbinska-Moneta et al., 1998; Robinson et al., 1966) and delays recovery time (Seiler et al., 2007). In this study, the proportion of time spent below LT-OBLA intensity was similar between the groups, but the proportion of time spent below the LT intensity tended to be greater (p = .09, ES = 1.33, *very likely*) in HRV-G than in BP. In addition, when the LnRMSSD was within the SWC, they trained continuously at high intermittent aerobic training prescription, which may have allowed them to spend time training at high intensity even during the short training time. When the LnRMSSD was within the individuals SWC, aerobic power was higher within the SWC than without the SWC (DeBlauw et al., 2021). Therefore, in this study, the HRV-guide training where high-intensity training was prescribed during better physiological states and low-intensity training was conducted to promote adequate recovery, may have led to improvements in maximal aerobic power despite the lower training load.

Regarding the initial level of LnRMSSD, individuals with high cardiac-parasympathetic activity exhibit high aerobic adaptations (Buchheit et al., 2010; Hautala et al., 2003). The LnRMSSD (4.43 ± 0.34) value in this study is equivalent to that reported in previous studies (4.20 to 4.61) (Carrasco-Poyatos et al., 2022; Javaloyes et al., 2020; Nuuttila et al., 2017). Furthermore, no group-related differences in LnRMSSD were observed in this study. Therefore, the effect of the initial LnRMSSD on the gain in maximal aerobic power may have been less in this study.

Regarding the training load, TRIMP and strain in the HRV-G was lower than in BP. TRIMP and strain were lower in HRV-G than in the BP because there was no period of intensive high-load training. To optimize aerobic power, intensive training period are necessary (Issurin, 2010; Thomas & Busso, 2005); however, intensive training may lead to increased training load (volume, monotony, and strain) (Figueiredo et al., 2019), resulting in training maladaptation for some individuals (Meeusen et al., 2013), thereby causing interindividual variation in the magnitude of training effects (Aubry et al., 2014; MORINAGA & TAKAI, 2024). Aubry et al. (2014) (Aubry et al., 2014) found that individuals who positive response to the 3-week intensive training exhibited greater gains in maximal aerobic power after the 2-week tapering than those who responded less or did not respond to the intensive training. The interindividual variation of training effects occurring such intensive training was dependent on the strain obtain from heart rate (MORINAGA & TAKAI, 2024). In this study variation of changes in aerobic powers was lower in HRV-G than BP. The magnitude of the strain depends not only on training volume but also on monotony, and lower monotony reduces strain, which can mitigate these risks (Foster, 1998). In this study, throughout the experimental period, there was no group difference in monotony between HRV-G and BP. Both groups having low monotony may be attributable to the fact that in the BP, intensive training periods and tapering periods were set, whereas in the HRV-G, it could be due to the training prescription at either low or high intensity. Therefore, HRV-training, which consists of both low-intensity and high-intensity components, allows for maintaining low monotony, thereby potentially maximizing aerobic power and reducing the variability of training effects.

The effect of submaximal aerobic power in this study was greater in HRV-G than in BP. HRV-guided training might have a greater impact on submaximal aerobic performance compared to predetermined aerobic training, as observed in recreational (da Silva et al., 2019; Vesterinen et al., 2016), trained (Javaloyes et al., 2019), and well-trained (Javaloyes et al., 2020) subjects. Above moderate-intensity exercise enhances sympathetic activity (Chwalbinska-Moneta et al., 1998; Robinson et al., 1966) and delays the time required for parasympathetic activity to return to resting levels (Seiler et al., 2007). Given that cardiac parasympathetic activity has been observed day to day variation (Carrasco-Poyatos et al., 2022; da Silva et al., 2019; DeBlauw et al., 2021; Kiviniemi et al., 2010; Nuuttila et al., 2017; Vesterinen et al., 2016), it is conceivable that even with the same external training load, a decrease in parasympathetic activity and an increase in sympathetic activity may be promoted. Therefore, it is suggested that the control of changes in over-activity of the autonomic nervous system by imposing a training load adapted to the fluctuating parasympathetic activity may affect the improvement of submaximal aerobic powers.

Training-induced changes in the indices of parasympathetic activity

$LnRMSSD_{7d}$ did not change before and after the experimental period both groups. Javaloyes et al. (2020) (Javaloyes et al., 2020) demonstrated that while LnRMSSD did not change with 8 weeks of aerobic training, it decreased more in BP compared with HRV-guided training. In aerobic training with the block periodization strategy, as the training volume decreased, the indicator of cardiac-parasympathetic activity decreased, whereas sympathetic activity increased, leading to a shift in the valance of parasympathetic and sympathetic activity toward sympathetic dominance (Manzi et al., 2009). Many earlier studies have demonstrated no change in LnRMSSD after <8-week of HRV-guided training (Carrasco-Poyatos et al., 2022; Da Silva et al., 2014; Javaloyes et al., 2019; Javaloyes et al., 2020; Nuuttila et al., 2017). A 12-week aerobic training program increases the cardiac-parasympathetic activity ((Melanson & Freedson, 2001). However, Nuuttila et al. (2017) (Nuuttila et al., 2017) showed that for an 8-week HRV-G training, RMSSD changed in the last four weeks, although it was unchanged in the first 4 weeks. In this study, the ratio of LF to HF, indicative of the valance of parasympathetic and sympathetic activity, increased in HRV-G and decreased in BP. Additionally, there were an inverted U-shaped relationship between training load and cardiac-parasympathetic activity. Considering these findings, HRV-guided training without moderate-intensity might be a training method that enhances cardiac-parasympathetic activity.

Limitations in this study

This study has some limitations. First, the classification of the participant groups in this study only level 3 based on the criteria defined by De Pauw et al. (2013) (De Pauw et al., 2013). The participants examined in this study were non-high-performing athletes (W_{max} < 4.6 W/kg, < level 3). Aerobic adaptation in high-performing athletes may differ from that in non-athletes (Skinner et al., 2001). Therefore, it is unknown whether the current results apply to elite athletes (W_{max} > 4.9 W/kg, levels 4-5) (De Pauw et al., 2013). Secondly, in this study, the low-intensity training was set at the LT intensity. Therefore, it is possible that the duration of exercise at moderate-intensity was not significantly reduced due to the increased heart rate during low-intensity training. Finally, the sample size of this study was small. Therefore, we used non-parametric analysis and magnitude-based inferences, which enables looking at small changes.

Practical applications

Aerobic training, designed as a predetermined program with BP, has an inter-individual variation in aerobic adaptation (Aubry et al., 2014; Skinner et al., 2001). In fact, the coefficient of variation of the relative change in maximal aerobic power is 49% for BP. The value for HRV-G is 35%. Therefore, HRV-G training showed less interindividual variation in aerobic power adaptation. Furthermore, HRV-G training combining low- and high-intensity, such as polarized training (Stöggl & Sperlich, 2015) decreases the time spent between moderate- and high-intensity training and the strain derived from the internal load. Earlier studies reported the effects of HRV-guided training of more than moderate intensity corresponding to the intensity from the LT to OBLA combined with a rest day in the case of two consecutive days of high-intensity training. In this study, high-intensity intermittent training was conducted when the LnRMSSD values were within the SWC of an individual. This may have resulted in a greater gain in maximal aerobic power.

CONCLUSION

The Heart rate variability-guided training without moderate-intensity training reduces training volume and uniformly enhances maximal and submaximal aerobic power.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by HM. YT participated in study design, coordinated research activities. The first draft of the manuscript was written by HM and YT commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL APPROVAL

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the National Institute of Fitness and Sports in Kanoya (No. 11-101).

CONSENT TO PARTICIPATE

Informed consent was obtained from all individual participants included in this study.

CONSENT TO PUBLISH

The authors affirm that human research participants provided informed consent for the publication of the images in Figure 1–4.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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