International Journal of Sports Physiology and Performance, (Ahead of Print)
https://doi.org/10.1123/ijspp.2024-0397

First Published Online: July 7, 2025

Human Kinetics
ORIGINAL INVESTIGATION

Substituting Low-Intensity Endurance Exercise With High-Intensity Microintervals: Responses to Acute Exercise

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Purpose: During very short (≤15 s) high-intensity (~100% maximum rate of oxygen uptake [VO_2]) intervals, defined here as microintervals, VO_2 and lactate concentrations can remain near the first lactate threshold (LT_1). However, no research has yet identified microinterval combinations that maintain acute responses entirely within the low-intensity zone below LT_1, accounting for oscillations caused by pulsating power output. ***Methods:*** Thirteen endurance athletes cycled for four 45-minute exercises: continuous low-intensity exercise (CON; power: 88% LT_1) and 3 microinterval exercises alternating 111% power associated to maximum rate of VO_2 and ~60 W, with cycles of 4–6, 7–23, and 10–20 s. ***Results:*** Compared with CON, heart rate and VO_2 did not exceed LT_1 more during microintervals ($P \geq .26$, effect size ≤ 0.44), and rating of perceived exertion was greater only during 10–20 s (3.1 [0.8] vs 2.4 [0.7], $P = .01$). Blood lactate and mean respiratory exchange ratio did not differ between exercises (analysis of variance $P \geq .36$). All mean responses of 4–26 and 7–23 were equivalent to CON ($P \leq .02$). Oscillation of the examined variables during microintervals was largely greater than CON only for heart rate (>100% greater; $P \leq .001$, effect size ≥ 1.7), while oscillation of VO_2 was at most 25% greater ($P \geq .02$, effect size ≤ 0.70). ***Conclusions:*** Microintervals could be classified as oscillating low-intensity exercises as they fulfill the traditional low-intensity criteria—responses of almost all internal variables did not exceed those of CON, not even fat oxidation. Microinterval exercises form a unique exercise class in which high-intensity muscular work blends with mild metabolic perturbation.

Keywords: low-intensity exercise, short high-intensity exercise, microinterval exercise, VO_2max

What makes endurance exercise "low-" or "high-intensity exercise?" Typically, intensities are divided into 3 zones using lactate/ventilatory thresholds: low- (LIT), moderate-, and high-intensity training (HIT) zones. Within this frame, low-intensity exercise is understood to be an exercise where intensity does not exceed that of the first lactate threshold (LT_1)[1]—as measured by internal variables, such as blood lactate, heart rate (HR), oxygen uptake (VO_2), and rating of perceived exertion (RPE) or external variables, such as power, and velocity. Compared with moderate-intensity training and HIT zones, LIT zone is characterized by greater reliance on fat oxidation[2] and type I muscle fibers,[3] steady pattern of VO_2 kinetics,[4] and reduced physiological strain.[5] Due to aforementioned factors, LIT allows to accumulate greater training volumes within the zone compared with higher intensities. While LIT exercise is mainly defined through internal variables, external variables like power and speed are also typically kept below the LT_1, making LIT exercise typically a continuous steady-paced session.

High intensity, that is, ~100% maximal VO_2 (VO_2max), is unsustainable for long durations in a single bout, so HIT is typically performed as short (10–60 s), or long (1–8 min) intervals.[6] Short HIT, with numerous work periods under 60 s and recovery typically below a 1:1 ratio, allows both substantial external high-intensity time and internal time spent close to VO_2max within a session.[6] Compared with long intervals, the greater accumulation of higher external intensity is believed to improve peripheral adaptations in both aerobic and neuromuscular systems after short HIT.[7]

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When the recovery period of short HIT is lengthened to a 1:1 and above, cardiopulmonary responses can fall below the second lactate threshold (LT_2), depending on the intensity of the recovery portion. Therefore, work–rest intervals such as the 20 to ~27 s[8] or 15 to 15 s[9] mimic internally moderate-intensity training zone exercises, even though they include a large portion of external high-intensity time. This finding raises a question that if the recovery time is further extended, and work time shortened, could short interval exercises mimic low-intensity exercise? In this study, such short intervals are defined as *microinterval exercises*, referring to high-intensity exercises with a work period of ≤15 s and an intensity of ~100% VO_2max combined with a recovery period of ≥ 1:2.

Interestingly, children's physical activity can be viewed as microinterval exercise. A typical free physical active play of young children is characterized by short bursts of different intensity activities (3–6 s) followed by periods of rest.[10] Thus, microintervals appear to be a natural and instinctive exercise pattern for humans. Microintervals were studied as part of interval training research in the 1960s[11,12] and 1970s.[13–15] In these studies, microinterval exercises indeed appeared to be counterparts to low-intensity exercise by involving low VO_2 and blood lactate. However, after the 1970s, this research branch has not been revisited much, with only occasional exceptions.[16] Despite the potential for increasing the cumulative external HIT time with low internal cardiopulmonary strain by doing microintervals, the awareness of the possibility of substituting LIT with microintervals is virtually nonexistent.

Since the definition of the LIT zone was not yet clearly defined in the 1970s, the aim of the present study was to investigate whether different work microinterval combinations can maintain cardiopulmonary responses entirely within the LIT zone. Of primary focus was the oscillation of cardiopulmonary variables during microinterval exercises and how these compared with those of continuous low-intensity exercise (CON).

Methods

Participants

A total of 13 regional to international level athletes were recruited to participate through personal invitation (Table 1). Among them, 5 were triathletes (all competing national level), 4 cyclists (1 international, 1 national, and 2 regional), 2 dog skijorer (both international), 1 runner (national), and 1 rugby player (international). All of them dedicated at least 40% of their training time to cycling. Participants were healthy and had not experienced any acute illnesses within 2 weeks before participation. The study was approved by the Ethical Committee of the University of Jyväskylä (1229/13.00.04.00/2022), compiled with the Declaration of Helsinki. All participants provided written informed consent.

Study Design

The study consisted of a maximal graded test and 4 different cycling exercise sessions. Each participant completed all 4 exercises—3 microintervals and a CON—at the same time of day (±2 h) in a randomized cross-over manner. There was at least 48 hours between the graded test and the exercises and 24 hours between the exercises. Before each session, participants were advised to keep the previous day light in terms of training and to abstain from alcohol and caffeine for 24 hours prior. Participants were instructed to have their meals consistently and at the same time before each workout, which was confirmed through inquiry.

Graded Test

Each participant did maximal graded test by cycling (Monark 894E, Monark Exercise AB). Before the test, body mass was measured (seca 719, seca GmbH & Co KG) with cycling gears and without shoes, and 300 g were subtracted as weight of the clothes. The initial power was 80 to 130 W, and cadence was freely chosen at the beginning of the test, but it was kept constant during the test. Length of a stage was 3 minutes, with an incremental of 20 to 30 W, calculated by an equation $8.91\,\frac{\text{m}}{\text{s}^2} \times 6\text{m} \times \text{cadence (rpm)} \times \text{load (kg)}$. Power output was measured with Favero Assioma Duo power meter (Favero Electronics Srl), which is reported to be a reliable power meter.[17] One participant did not have a power meter in graded test, and her threshold powers and maximal aerobic power (P_{max}) were later estimated by Favero Assioma power meter by cycling with the same cadence.

Gas exchanges (Vyntus CPX Metabolic Cart, Vyaire Medical GmbH), fingertip lactate (analyzed with EKF-diagnostic GmbH), HR (HRM-pro belt together with Fenix 6 monitor, Garmin Ltd), and power (Favero Assioma Duo) were measured and averaged during the last minute of each stage. The graded test was terminated when the participant was no longer able to maintain the chosen cadence. The LT_1 was set at 0.3 mmol/L above the lowest lactate value and the LT_2 at the intersection point between (1) a linear model between LT_1 and the next lactate point and (2) a linear model for the lactate points measured after the point when lactate increased at least 0.8 mmol/L for the first time. These methods have been used before.[18] VO_2max was the highest average minute of VO_2, and P_{max} was defined as the weighted mean of the last 3 minutes of the test: power of last completed stage (in watts) + (time [in seconds] of unfinished state)/(180 s) × increment (in watts). Following the graded test, the participants familiarized themselves with the microintervals for 30 minutes.

Exercises

Exercises were done with Monark 894E ergometer, except for 2 participants, which did their CON exercise with Monark LC4 (Monark Exercise AB). Before each exercise, the participants warmed up for 5 minutes using the initial load from the graded test. During the 45-minute exercises (Figure 1), measurements were taken at 5-second intervals for VO_2, respiratory exchange ratio (RER; Vyntus CPX), and cardiac stroke volume (SV; Physioflow PF-07 Enduro, Manatec Biomedical) and at 1-second intervals for HR (Garmin HRM-pro and Fenix 6) and power (Assioma Duo). Cardiopulmonary measurements were collected for 3 consecutive minutes ending at 14:30, 29:30, and 44:30. Additionally, Borg RPE (0–10) Scale[19] and fingertip blood lactate sample (analyzed with EKF-diagnostic) were collected after these measurement intervals. All exercises took place in the same

Table 1 Participant Characteristics, Mean (SD)

	Females	Males	Combined
n	6	7	13
Age	26 (5)	28 (7)	27 (6)
Height, cm	166 (6)	183 (7)	175 (11)
Body mass, kg	60.9 (4.1)	76.9 (8.3)	69.7 (10.5)
Power at LT_1, W	156 (23)	215 (40)	188 (44)
VO_2 at LT_1, L/min	2.2 (0.3)	2.9 (0.4)	2.6 (0.5)
HR at LT_1, beats/min	150 (10)	143 (17)	146 (14)
Power at LT_2, W	206 (27)	288 (35)	250 (52)
P_{max}, W	262 (26)	367 (35)	318 (62)
VO_2max, L/min	3.2 (0.4)	4.6 (0.4)	3.9 (0.8)
VO_2max, mL/kg/min	53.0 (3.1)	59.5 (7.4)	56.5 (6.6)

Abbreviations: HR, heart rate; LT_1, first lactate threshold; LT_2, second lactate threshold; P_{max}, maximal aerobic power; VO_2, oxygen uptake; VO_2max, maximal VO_2.

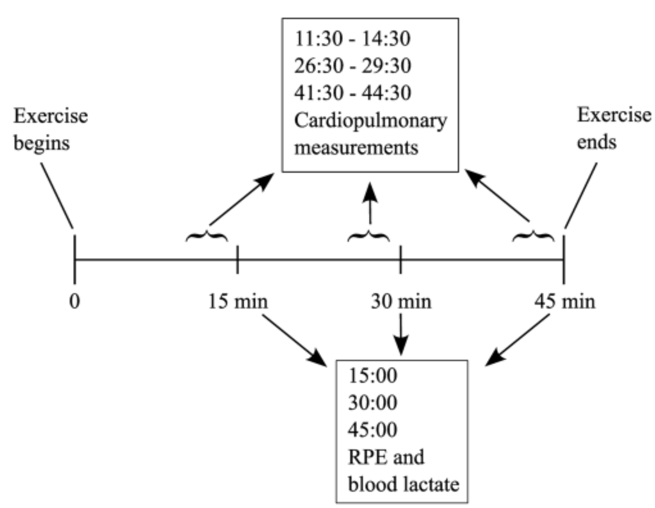

Figure 1 — Procedure during the exercises. RPE indicates rating of perceived exertion.

laboratory room under similar temperature (20.1 [0.8] °C) and humidity (19% [6%]) conditions. The mean temperature difference per participant was 0.9 °C (maximum: 1.8 °C), and the mean humidity difference was 12% (maximum: 19%).

Oscillation

To quantify the fluctuation by the pulsating power output, oscillation was calculated as the SD of each measured variables during each of the three 3-minute measurement periods.

Microinterval Exercises

Each participant completed three 45-minute long microinterval exercises with different work:rest ratios. The work interval began every 30 seconds with the following configurations (time as seconds) to work:rest durations: 4:26 seconds (4–26), 7:23 seconds (7–23), and 10:20 seconds (10–20). A total of 88 high-intensity intervals were completed in a single microinterval session. Two high-intensity intervals that would have occurred at 15:30 and 30:30 were omitted to facilitate fingertip blood sampling (cf. Figure 2). The weight in the Monark 894E at the high-intensity work interval was prescribed as 105% of the weight at $P_{max} + 200$ g and rounded to nearest 100 g. This led to intensity 111% (2%) of P_{max}. During the recovery interval the power was the internal load of the ergometer (typically 50–70 W, depending on cadence). Examples of power output, HR, VO_2, and RER during CON and 7–23 microinterval exercise are presented in Figure 2.

Continuous Low-Intensity Exercise

The weight in the Monark 894E was prescribed as 85% of the weight at LT_1-100 g and rounded down at 100 g, so that the intensity of the 45-minute long continuous exercise was 88% (4%) of the power at the LT_1. The cadence was freely chosen but constant during CON. The power oscillation (SD of the power) during CON was 9 (2) W. CON and microinterval exercises were not designed to have the same mean power. The study aimed to assess whether responses to different microinterval exercises would exceed the LIT zone. Therefore, the CON condition was selected from the upper end of the LIT zone.

Statistics

All values are expressed as mean and SD. Normal distribution of the data was checked with the Shapiro–Wilk test and homogeneity of the variances by Levene test. A 1-way repeated measures analysis of variance was used to compare training load variables measured during training sessions. A 2-way repeated measures analysis of variance was performed to examine the interaction (training type × time) across measured variables. In a case of significant training type × time interaction, relative changes were compared between training types using paired samples *t* test. As suggested, no single *P* value threshold of significance was chosen.[20] In the figures, all *P* values less than .10 were displayed. Normality assumption was violated in HR and VO_2 time above LT_1

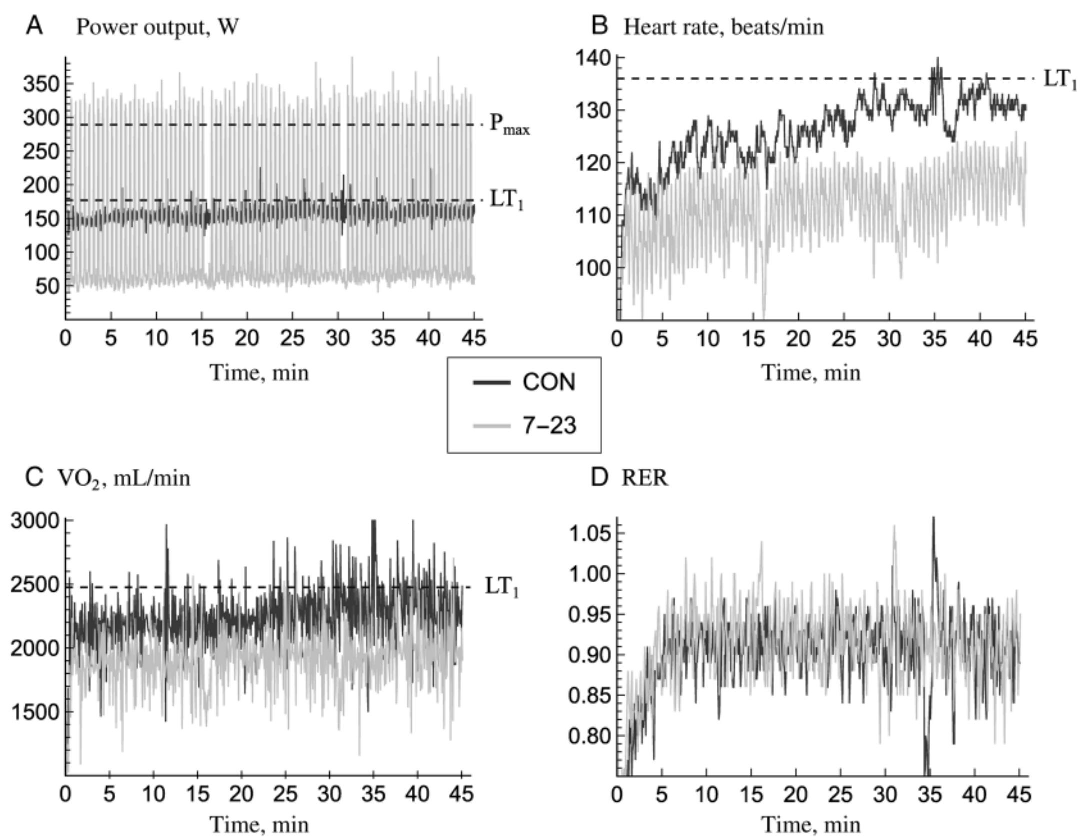

Figure 2 — Examples of 45-minute CON and 7–23 microinterval exercises in 1 participant. (A) Power output. The 2 omitted intervals in 7–23 assisted obtaining fingertip blood sample. (B) HR. HR exceeded LT_1 for 35 seconds in CON. Microinterval had such regular HR oscillation that it could be estimated by sinusoidal curve. (C) VO_2. VO_2 exceeded LT_1 for 6.5 minutes in CON and 40 seconds in 7–23. (D) RER. 7–23 indicates microinterval alternating 7-second work and 23-second recovery; CON, conventional low-intensity exercise; HR, heart rate; LT_1, first lactate threshold; RER, respiratory exchange ratio; VO_2, oxygen uptake.

and average RER and SV oscillations. For them, Friedman test was used for group comparison; Wilcoxon signed-rank test was used for within-group and Mann–Whitney *U* test for between-group comparisons. To further analyze the magnitude of observed changes, the effect size (ES) was assessed by Hedges *g* and after nonparametric tests by a formula: $Z/\sqrt{n}$, where *Z* is the *z* score and n are the number of observations on which *Z* is based. As this corresponds to point biserial *r*, an analytical conversion is made to represent it as *d*-family ES[21]:

$$\mathrm{ES} = \frac{2r}{\sqrt{(1-r^2)}}.$$

ES for between-groups differences was calculated by subtracting within-group ESs from each other. Small, moderate, large, and very large ES magnitudes for Hedges *g* were categorized as 0.20, 0.50, 0.80, and 1.2. Analyses were performed with IBM SPSS Statistics v.29, Microsoft Excel 2010, or Mathematica 13.0 (Wolfram Research).

Average values (also average oscillation) from exercises were calculated by taking average value from all 3 measurements points (15, 30, and 45 min). Linear regression was used to examine the relationship between average power, average HR, and average VO_2. For each participant, 2 regression lines were calculated—one between power and HR and another between power and VO_2—using data from all 4 exercises. The R^2 values for each line were calculated and averaged.

One-sample, 1-sided *t* test was used as post hoc for equivalence testing of all average values and oscillations that did not differ from CON. Lower margins for the difference between CON and microintervals were not used, as LIT zone was assumed to extend down to zero. Upper margins for oscillations were set as half of the 95% CI length of CON, being 0.0075 for RER and 1.4% for VO_2. For average values, margins were chosen as typical errors, with 0.03 for RER,[22] 0.35 mmol/L for blood lactate concentration,[23] 7 mL for SV,[24] and 0.3 for RPE.[23] Typical errors for times above LT_1 were calculated using intraclass correlation coefficient, with the equation: $\text{typical error} = \text{SD} \times \sqrt{1-\text{ICC}}$, and they were 3.8% for VO_2[23] and 2.2% for HR.[23]

Results

Mean characteristics of different exercise sessions are presented in Table 2.

Average Physiological and Perceptual Responses

The average values of CON and 10–20 differed only in RPE ($P = .01$ and $\text{ES} = 0.8$; otherwise $P > .10$). Average values of HR, VO_2, and SV were lower in 4–26 and 7–23 compared with CON or 10–20 ($P \leq .09$, $\text{ES} \geq 0.8$). RER and blood lactate did not differ between the exercises (group interaction $P > .35$; Figure 3).

Linear regression between average power and average absolute VO_2 (mL/min) for each participant revealed that the mean coefficients for an equation $VO_2(\text{mL/min}) = a \times \text{P(W)} + b$ were 9.2 (1.1) for *a* and 841 (163) for *b*, and the mean R^2 for the linear regression was .95 (.04). Mean R^2 of the connection between average power and average HR was .89 (.13).

Average Oscillation of Physiological Responses

HR oscillation was largely lower ($P < .001$, $\text{ES} \geq 1.7$) in CON compared with any of the microintervals. Similarly, SV oscillation was lower ($P \leq .02$, $\text{ES} \geq 0.7$) in CON compared with any of the microintervals, although the difference was more moderate than with HR. VO_2 oscillation of 7–23 and 10–20 was moderately higher than CON or 4–26 ($P \leq .05$, $\text{ES} = 0.6–0.7$). RER oscillation did not differ between exercises (group interaction $P = .25$; Figure 4).

The amount of time HR and VO_2 exceeded LT_1 did not differ between CON and 10–20 ($P > .25$), while the 4–26 and 7–23 were mostly below these 2 ($P < .10$, $\text{ES} \geq 0.8$; Table 3).

Equivalence Testing

Compared with CON, 10–20 was not below the upper margin ($P > .52$) in average responses of RPE, VO_2, or HR time above LT_1. All other average responses and microintervals were below upper margin ($P < .02$, $\text{ES} < -0.60$; Table 4), when compared with CON. Compared with CON, no microinterval was below the upper margin of RER oscillation ($P > .11$; Table 4).

Discussion

The main finding of the study was that cycling microinterval exercises with ≤10-second work interval at 111% P_{max} intensity and recovery periods greater than 1:2 can mostly be considered equivalent to low-intensity exercises when assessing internal cardiopulmonary variables. This was true, even though external power output accumulated a large amount of time above LT_2. Another finding was that HR oscillated very largely during the microinterval exercises compared with CON, while other examined variables (VO_2, RER, and SV) did not show as strong oscillation pattern. Microinterval exercises seem plausible alternative to accumulate great amount of external HIT time with mild metabolic and cardiovascular demands.

Physiological and Perceptual Responses

The longer the microinterval, the larger the average values of HR, VO_2, SV, and RPE. In fact, average power had a strong linear connection to average VO_2 and HR in our study, with $R^2 > .89$. This is understandable, as both HR and VO_2 are primarily influenced by

Table 2 Power Characteristics of Different Exercises, Mean (SD)

	Mean power (realized), W	Mean power (designated), W	Mean power (realized), % LT_1	Power above LT_2 (realized), %	Power above P_{max} (realized), %	Power above LT_2 and P_{max} (designated), %
CON	165 (38)	166 (38)	88 (4)	0	0	0
4–26	93 (24)	94 (9)	50 (8)	12 (1)	7 (2)	13
7–23	125 (30)	123 (15)	67 (7)	21 (1)	15 (3)	23
10–20	151 (32)	153 (22)	81 (9)	31 (2)	23 (7)	32

Abbreviations: CON, continuous low-intensity exercise; LT_1, first lactate threshold; LT_2, second lactate threshold; P_{max}, power associated to maximal oxygen uptake. Note: 4–26, 7–23, and 10–20 are microintervals.

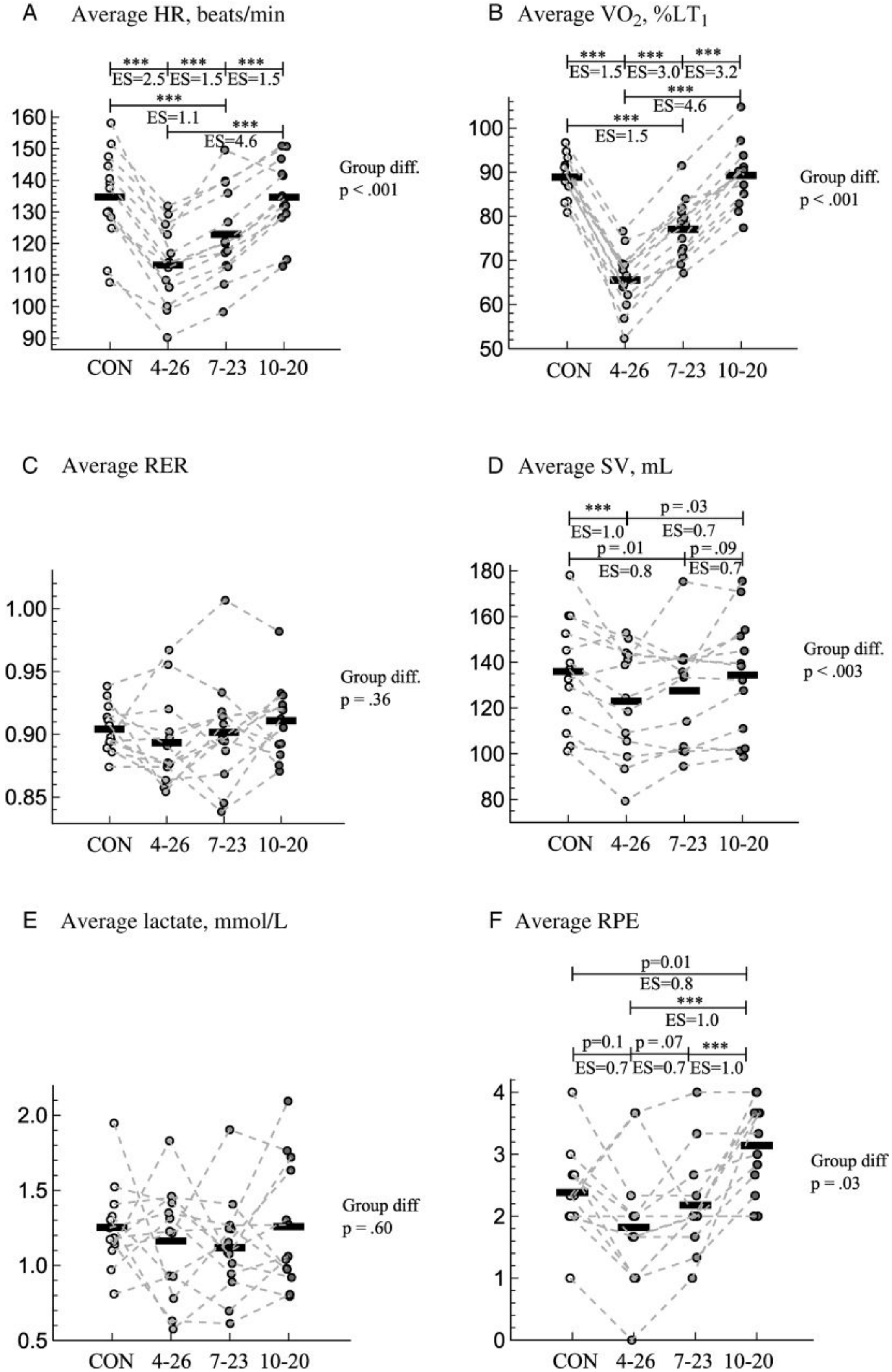

Figure 3 — Average values of (A) HR, (B) VO_2, (C) RER, (D) SV, (E) blood lactate, and (F) RPE. In the figures, the mean values are represented by the black thick lines and individual values by circles. To the right side of each figure, group interaction *P* value is reported. If a group difference was found, all pairwise comparisons with $P \leq .10$ are shown. 4–26, 7–23, and 10–20 are microinterval exercises. CON indicates continuous low-intensity exercise; ES, effect size; HR, heart rate; RER, respiratory exchange ratio; RPE, rating of perceived exertion; SV, stroke volume; VO_2, oxygen uptake. $^{***}P < .005$.

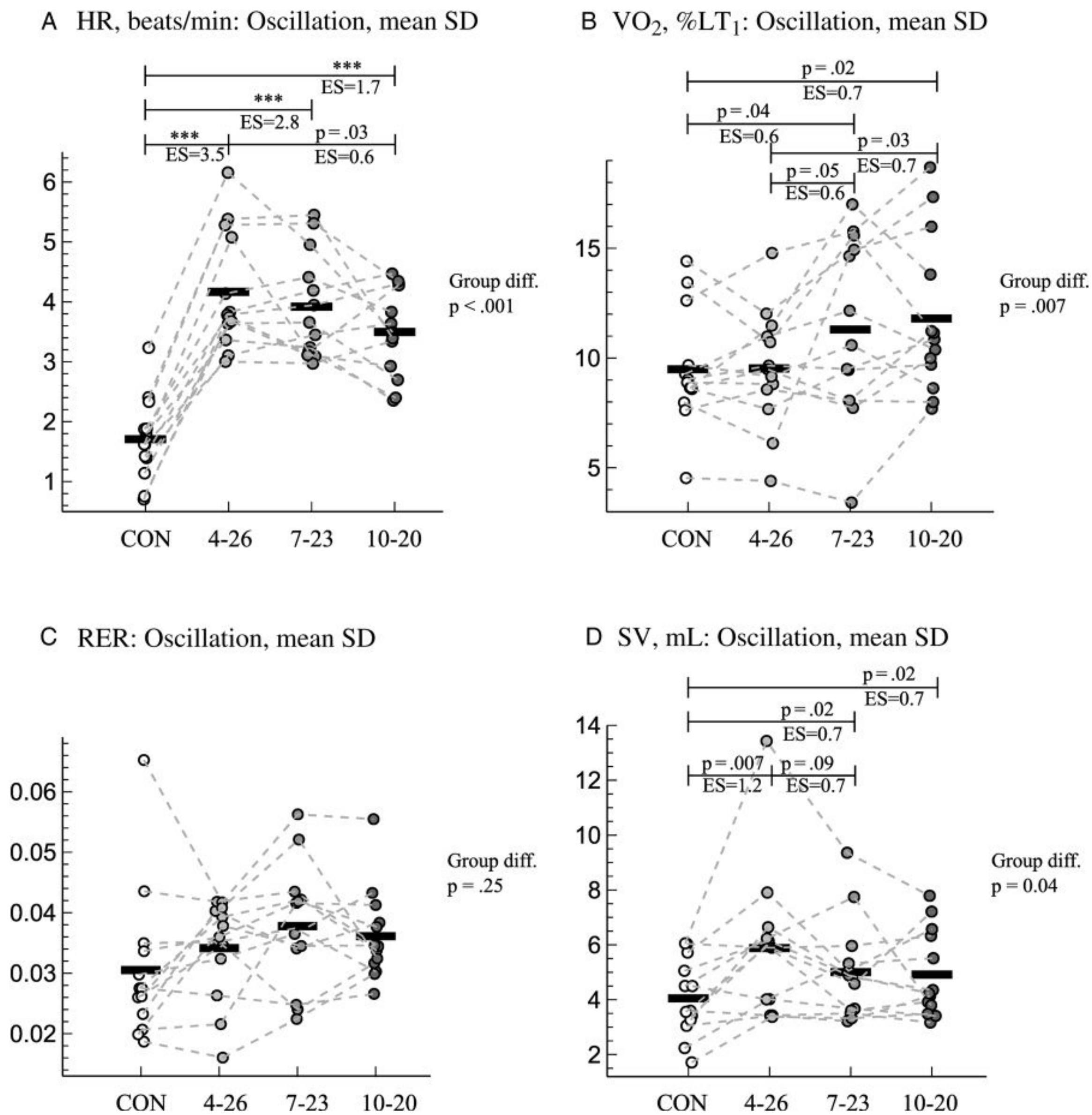

Figure 4 — Average oscillation (mean SD of a measured variable) of (A) HR, (B) VO_2, (C) RER, and (D) SV during the exercises. In the figures, mean values are plotted as the black thick lines and individual values by circles. To the right side of each figure, group difference with analysis of variance or, in the case of violated normality, Friedman is shown. If a group difference was found, all pairwise comparisons with $P \le .10$ are shown. 4–26, 7–23, and 10–20 are microintervals. CON indicates continuous low-intensity exercise; ES, effect size; HR, heart rate; RER, respiratory exchange ratio; SV, stroke volume; VO_2, oxygen uptake. $^{***}P < .005$.

the average power output in any exercise. Even a 6 × 3-minute high-intensity interval exercise can result in similar average HR and VO_2 values as a steady-state exercise of the same average external intensity.[25] Since the average power output in our study was below LT_1, it was expected that the average HR and VO_2 would also be below LT_1. Blood lactate concentrations after microintervals were equivalent to that of CON, indicating low metabolic stress during the work intervals, which has been a common observation when using microintervals.[12–16,26]

The 4–26 and 7–23 exercises remained below LT_1 for measured variables, even considering the oscillations in physiological responses. Moreover, 10–20 was at the threshold: It did not differ from CON but was neither equivalent, as, for example, time spent above LT_1 in terms of HR and VO_2 had notably increased. Interestingly, for all microinterval exercises, average RER values were equivalent to that of CON, which has also been observed previously with 30 to 30 short intervals.[27]

The seminal studies on microintervals proposed that during the work interval, most muscle energy comes aerobically from myoglobin stores, which are replenished during recovery.[11,14,15,26] Compared with other studies, a 20-second work period with a 1:6 rest increased blood lactate concentration above LT_1, although HR response was similar to LIT. In contrast, 15- to 30-second microintervals can maintain blood lactate concentration at resting levels.[12] These findings indicate that when mimicking the LIT zone with microintervals, the work period duration may be more crucial than the rest period. Depending on intensity, 15 seconds seems to be the time limit after which the oxygen from the myoglobin stores is depleted and the body starts to rely more on anaerobic energy production.

Typically, short HIT protocols have been viewed as strenuous exercises aimed to maximize the time spent near VO_2max,[28] or they have been compared with other HIT protocols.[29] Ideas that very short HIT, that is, microintervals, could be comparable to LIT, have been studied in recent years only by Wallner et al,[16] with 10 to 20 running microinterval using work intensities ranging from 91% to 110% of velocity at VO_2max. In their study, 10 to 20 microintervals at 110% velocity at VO_2max clearly exceeded LT_1; whereas in our study, 10 to 20 at 111% P_{max} was at LT_1. This difference may be due to exercise mode. Running requires supporting body mass even during recovery, increasing overall muscular work. Also, the acceleration and deceleration phases may be longer, leading to shorter recovery times compared with cycling. Additionally, running can result in faster VO_2 kinetic responses than cycling.[30] Hopefully, future studies may clarify these mode-dependent responses.

Table 3 Portion of Time That HR and VO_2 Were Above LT_1, Mean (SD)

	HR above LT_1, %	VO_2 above LT_1, %
CON	3 (7)	13 (10)
4–26	0	1 (1)
7–23	0.1 (0.3)	5 (6)
10–20	5 (11)	18 (16)
Difference between		
CON vs 4–26	**P = .03, ES = 0.9**	**P = .001, ES = 1.5**
CON vs 7–23	**P = .09, ES = 1.7**	**P = .002, ES = 1.5**
CON vs 10–20	P = .58, ES = 0.2	P = .26, ES = 0.4
4–26 vs 7–23	P = .18, ES = 0.5	**P = .004, ES = 2.9**
4–26 vs 10–20	**P = .04, ES = 2.0**	**P = .001, ES = 1.5**
7–23 vs 10–20	**P = .05, ES = 0.8**	**P = .001, ES = 1.5**

Abbreviations: CON, continuous low-intensity exercise; HR, heart rate; LT_1, first lactate threshold; VO_2, oxygen uptake. Note: 4–26, 7–23, and 10–20 are microintervals. All differences with $P < .10$ have been bolded.

Oscillation of Physiological Responses

HR exhibited very large oscillations during microintervals, exceeding the levels in CON by over 100%. Although HR and VO_2 are usually strongly correlated, unexpectedly VO_2 oscillation was only 25% greater during microinterval exercises compared with CON. One possible explanation is that the high external power output during the work intervals induced excess postexercise oxygen consumption. Its rapid component consists of replenishment of myoglobin stores; resynthesis of adenosine triphosphate and creatine phosphate; and increased ventilation, body temperature, and circulation.[31] These factors likely prevented a decline in VO_2 during the brief recovery periods, keeping VO_2 surprisingly stable throughout microinterval exercises. Difference in RER oscillation was even lower than in VO_2 and did not differ from CON, though it was not equivalent either. Hence, if the aim of the

Table 4 Equivalence Testing

	Upper margin for the difference	Microinterval exercise	Difference from CON	P (below margin)	ES (difference from margin)
VO_2 time above LT_1, %	3.8	4–26	−12.1 (8.7)	<.001	−1.72
		7–23	−8.0 (5.8)	<.001	−1.91
		10–20	4.4 (12.0)	.57	0.05
HR time above LT_1, %	2.2	4–26	−3.1 (6.9)	.01	−0.72
		7–23	−3.0 (6.9)	.01	−0.70
		10–20	2.4 (14.1)	.52	0.14
RER	0.03	4–26	−0.01 (0.03)	<.001	−1.11
		7–23	−0.00 (0.04)	.01	−0.71
		10–20	0.01 (0.03)	.01	−0.65
Blood lactate, mmol/L	0.35	4–26	−0.09 (0.50)	.004	−0.83
		7–23	−0.13 (0.37)	<.001	−1.22
		10–20	0.00 (0.50)	.02	−0.64
RPE	0.3	4–26	−0.6 (1.0)	.004	−0.83
		7–23	−0.2 (0.8)	.02	−0.61
		10–20	0.8 (0.9)	.95	0.47
Stroke volume, mL	7	4–26	−12 (12)	<.001	−1.53
		7–23	−8 (10)	<.001	−1.42
		10–20	−2 (13)	.02	−0.60
RER oscillation	0.0075	4–26	0.004 (0.011)	.11	−0.33
		7–23	0.007 (0.010)	.46	−0.03
		10–20	0.006 (0.010)	.24	−0.19
VO_2 oscillation, % LT_1	1.6	4–26	0.0 (1.7)	.007	−0.76

Abbreviations: CON, continuous low-intensity exercise; ES, effect size; HR, heart rate; LT_1, first lactate threshold; RER, respiratory exchange ratio; RPE, rating of perceived exertion; VO_2, oxygen uptake. Note: 4–26, 7–23, and 10–20 are microintervals. Mean (SD) of how much oscillations of microintervals differ from that of CON. The margin is taken from literature, except for oscillations, where the 95% CI length of the CON oscillation was used. The P value, together with ES, tests whether the difference is below the upper margin.

LIT exercise is to have a sufficiently stable VO_2 and RER response, microintervals seem to be surprisingly good alternative.

The "normal" physiological oscillation during CON was surprisingly large. For example, VO_2 and SV oscillations were only ~20% less than those observed during 10–20 and no difference in RER oscillation. This highlights that steady-state cycling responses are not very constant, as noted before.[32] Therefore, apart from HR, the oscillations induced by microintervals in physiological variables surprisingly closely resembles those of "steady" low-intensity exercise. One could argue that from cardiopulmonary point of view, microintervals are slightly more oscillatory form of low-intensity exercise. Another surprising finding was the lack of systematic differences in oscillations between various microintervals, despite a wide range in work-to-rest ratios.

Microinterval Exercise as Low-Intensity Exercise

As microinterval exercises mostly mimic internally LIT exercises and externally HIT exercises, they present a compelling approach to test the definition of low-/high-intensity exercise. There is evidence supporting intensity-dependent responses across various domains, including mitochondrial adaptations,[33] and gene expressions.[34] The classification of what constitutes low- or high-intensity exercise significantly influences the interpretation of such "intensity-dependent" claims. It would be critical to clarify whether these responses are driven by internal intensity associated with metabolic perturbation or external intensity linked to muscle contractions and total energy flux.

If the premise that energy during the microinterval exercise is aerobic exploiting myoglobin holds true, it would suggest that during microinterval exercises, muscle operates at or near 100% VO_2max. However, since microintervals do not cause significant metabolic perturbation, muscle biopsies or interventions are needed to confirm if this could translate into superior peripheral endurance adaptations compared with LIT.

Additionally, it has been hypothesized that the high power output during short HIT stimulates the neuromuscular system.[7] Thus, microintervals may enhance neuromuscular capacity with minimal metabolic cost. After all, microintervals recruit fast-twitch muscle fibers, which are minimally activated during low-intensity exercise.[35] If nothing else, substituting LIT with microintervals provides athletes with valuable training variation.[36]

Given the low RPE and blood lactate concentration, we could speculate that microintervals in this study may mimic low-intensity exercise even in longer sessions. However, there is a risk that in less experienced athletes, the pulsating power may lead to faster fatigue, higher blood lactate, increased RPE, and more pronounced cardiac drift that elevates HR time above LT_1.

Limitations

With a small sample size (n = 13), there is a risk of bias, inaccuracy, or overestimation both in average response as well as variable oscillations. However, the average responses of the microintervals were consistent. For example, average HR and VO_2 responses fit well to a linear regression line, supporting the validity of the average responses. In addition, comparison of the current CON oscillation with low-intensity exercise (n = 44, ~85% LT_1) from our earlier study[37] shows similar RER (0.031 [0.012] vs 0.035 [0.011]) and VO_2 oscillations (9.5% [2.6%] vs 9.7% [3.8%]), with no significant difference ($P > .11$), supporting the validity of the present study's oscillation data.

With the Monark 894E ergometer, initial power overshoots may happen at the onset of work interval. These are corrected over a few seconds, leading to the desired average power output. However, this may cause some cyclists to experience more sprint-like intervals than planned. While microintervals appear to mimic low-intensity exercise in the short term, longer training studies are needed to determine if they are chronically more demanding and how they compare to traditional methods.

Practical Applications

Low-intensity exercises can be replaced with suitable microintervals without altering acute cardiopulmonary responses. This approach allows for the inclusion of a potentially high amount of high-intensity neuromuscular system stimulation in a training week, while keeping the physiological strain minimal. Replacing some low-intensity exercises with microintervals could also provide a source of variation in endurance training.

Conclusions

Typically, low- and high-intensity exercises are easily distinguishable. However, our study shows that although microintervals are externally categorized as high-intensity exercise, their internal cardiopulmonary, metabolic, and perceived-exertion responses can mostly mimic low-intensity exercise. This is because the acute responses remain below the LT_1, even when accounting for their oscillatory nature. It follows that executing exercise that fulfills the traditional low-intensity criteria—where internal variables remain below LT_1—appears to be possible even with microintervals comprising more than 20% of the time above LT_2.

Hence, the concept of "low-intensity exercise" may not be as clear-cut as commonly presumed. Thus, microinterval exercises form a unique exercise class in which high-intensity muscular work blends with very mild metabolic perturbation. As such, microintervals appear to be an intriguing type of interval training that could be further explored in research and endurance training.

Acknowledgment

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. Seiler S, Tønnessen E. Intervals, thresholds, and long slow distance: the role of intensity and duration in endurance training. *Sportscience*. 2009;13(13):32–53.
2. Holloszy JO. The regulation of carbohydrate and fat metabolism during and after exercise. *Front Biosci*. 1998;3(4):1011–1027. doi:10.2741/A342
3. Sale DG. Influence of exercise and training on motor unit activation. *Exerc Sport Sci Rev*. 1987;15(1):95–152.
4. Xu F, Rhodes EC. Oxygen uptake kinetics during exercise. *Sports Med*. 1999;27(5):313–327. PubMed ID: 10368878 doi:10.2165/00007256-199927050-00003
5. Matomäki P, Nuuttila OP, Heinonen OJ, Kyröläinen H, Nummela A. How to equalize high- and low-intensity endurance exercise dose. *Int J Sports Physiol Perform*. 2024;19(9):851–859. PubMed ID: 39032919 doi:10.1123/ijspp.2024-0015

6. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: part I: cardiopulmonary emphasis. *Sports Med*. 2013;43(10):927–954. PubMed ID: 23832851 doi:10.1007/s40279-013-0066-5
7. Rønnestad BR, Hansen J, Vegge G, Tønnessen E, Slettaløkken G. Short intervals induce superior training adaptations compared with long intervals in cyclists—an effort-matched approach. *Scand J Med Sci Sports*. 2015;25(2):143–151. PubMed ID: 24382021 doi:10.1111/sms.12165
8. Tschakert G, Kroepfl J, Hofmann P, Mueller A, Moser O, Groeschl W. How to regulate the acute physiological response to "aerobic" high-intensity interval exercise. *J Sports Sci Med*. 2015;14:29–36. PubMed ID: 25729286
9. Helgerud J, Høydal K, Wang E, et al. Aerobic high-intensity intervals improve VO_2max more than moderate training. *Med Sci Sports Exerc*. 2007;39(4):665–671. PubMed ID: 17414804 doi:10.1249/mss.0b013e3180304570
10. Bailey RC, Olson J, Pepper SL, Porszasz J, Barstow TJ, Cooper DM. The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc*. 1995;27(7):1033–1041. PubMed ID: 7564970 doi:10.1249/00005768-199507000-00012
11. Åstrand I, Åstrand P-O, Christensen EH, Hedman R. Myohemoglobin as an oxygen-store in man. *Acta Physiol Scand*. 1960;48(3–4):454–460. doi:10.1111/j.1748-1716.1960.tb01880.x
12. Christensen EH, Hedman R, Saltin B. Intermittent and continuous running (A further contribution to the physiology of intermittent work). *Acta Physiol Scand*. 1960;50(3–4):269–286. doi:10.1111/j.1748-1716.1960.tb00181.x
13. Edwards RHT, Melcher A, Hesser CM, Wigertz O. Blood lactate concentrations during intermittent and continuous exercise with the same average power output. In: Pernow B, ed. *Muscle Metabolism During Exercise: Proceedings of a Karolinska Institutet Symposium Held in Stockholm, Sweden, September 6–9, 1970 Honorary Guest: E Hohwü Christensen*. Springer. 1971:425–428.
14. Essén B, Hagenfeldt L, Kaijser L. Utilization of blood-borne and intramuscular substrates during continuous and intermittent exercise in man. *J Physiol*. 1977;265(2):489–506. PubMed ID: 850204 doi:10.1113/jphysiol.1977.sp011726
15. Saltin B, Essen B. Muscle glycogen, lactate, ATP, and CP in intermittent exercise. In: Pernow B, ed. *Muscle Metabolism During Exercise: Proceedings of a Karolinska Institutet Symposium Held in Stockholm, Sweden, September 6–9, 1970 Honorary Guest: E Hohwü Christensen*. Springer; 1971:419–424.
16. Wallner D, Simi H, Tschakert G, Hofmann P. Acute physiological response to aerobic short-interval training in trained runners. *Int J Sports Physiol Perform*. 2014;9(4):661–666. PubMed ID: 24231625 doi:10.1123/ijspp.2013-0385
17. Rodríguez-Rielves V, Lillo-Beviá JR, Buendía-Romero Á, et al. Are the assioma favero power meter pedals a reliable tool for monitoring cycling power output? *Sensors*. 2021;21(8):2789. doi:10.3390/s21082789
18. Nuuttila OP, Nummela A, Häkkinen K, Seipäjärvi S, Kyröläinen H. Monitoring training and recovery during a period of increased intensity or volume in recreational endurance athletes. *Int J Environ Res Public Health*. 2021;18(5):2401. doi:10.3390/ijerph18052401
19. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377–381. PubMed ID: 7154893 doi:10.1249/00005768-198205000-00012
20. Wasserstein RL, Schirm AL, Lazar NA. Moving to a world beyond "p<0.05." *Am Stat*. 2019;73:1–19. doi:10.1080/00031305.2019.1583913
21. McGrath RE, Meyer GJ. When effect sizes disagree: the case of r and d. *Psychol Methods*. 2006;11(4):386–401. PubMed ID: 17154753 doi:10.1037/1082-989X.11.4.386
22. Achten J, Jeukendrup AE. Maximal fat oxidation during exercise in trained men. *Int J Sports Med*. 2003;24(8):603–608. PubMed ID: 14598198 doi:10.1055/s-2003-43265
23. Yogev A, Arnold J, Nelson H, et al. Comparing the reliability of muscle oxygen saturation with common performance and physiological markers across cycling exercise intensity. *Front Sports Act Living*. 2023;5:1143393. doi:10.3389/fspor.2023.1143393
24. Gordon N, Abbiss CR, Maiorana AJ, Marston KJ, Peiffer JJ. Intrarater reliability and agreement of the physioflow bioimpedance cardiography device during rest, moderate and high-intensity exercise. *Kinesiology*. 2018;50:140–149.
25. Bartlett JD, Close GL, MacLaren DPM, Gregson W, Drust B, Morton JP. High-intensity interval running is perceived to be more enjoyable than moderate-intensity continuous exercise: implications for exercise adherence. *J Sports Sci.* 2011;29:547–553. doi:10.1080/02640414.2010.545427
26. Åstrand I, Åstrand P-O, Christensen EH, Hedman R. Intermittent muscular work. *Acta Physiol Scand*. 1960;48(3–4):448–453. doi:10.1111/j.1748-1716.1960.tb01879.x
27. Eigendorf J, Maassen M, Apitius D, Maassen N. Energy metabolism in continuous, high-intensity, and sprint interval training protocols with matched mean intensity. *J Strength Cond Res*. 2021;35(11):3104–3110. PubMed ID: 31714453 doi:10.1519/JSC.0000000000003308
28. Thevenet D, Leclair E, Tardieu-Berger M, Berthoin S, Regueme S, Prioux J. Influence of recovery intensity on time spent at maximal oxygen uptake during an intermittent session in young, endurance-trained athletes. *J Sports Sci*. 2008;26(12):1313–1321. PubMed ID: 18821267 doi:10.1080/02640410802072697
29. Rønnestad BR, Hansen J. Optimizing interval training at power output associated with peak oxygen uptake in well-trained cyclists. *J Strength Cond Res*. 2016;30(4):999–1006. PubMed ID: 23942167 doi:10.1519/JSC.0b013e3182a73e8a
30. Hill DW, Halcomb JN, Stevens EC. Oxygen uptake kinetics during severe intensity running and cycling. *Eur J Appl Physiol*. 2003;89(6):612–618. PubMed ID: 12759759 doi:10.1007/s00421-002-0779-x
31. Børsheim E, Bahr R. Effect of exercise intensity, duration and mode on post-exercise oxygen consumption. *Sports Med*. 2003;33(14):1037–1060. PubMed ID: 14599232 doi:10.2165/00007256-200333140-00002
32. Lamarra N, Whipp BJ, Ward SA, Wasserman K. Effect of interbreath fluctuations on characterizing exercise gas exchange kinetics. *J Appl Physiol.* 1987;62:2003–2012. doi:10.1152/jappl.1987.62.5.2003
33. Lundby C, Jacobs RA. Adaptations of skeletal muscle mitochondria to exercise training. *Exp Physiol*. 2016;101(1):17–22. PubMed ID: 26440213 doi:10.1113/EP085319
34. Popov DV, Makhnovskii PA, Kurochkina NS, Lysenko EA, Vepkhvadze TF, Vinogradova OL. Intensity-dependent gene expression after aerobic exercise in endurance-trained skeletal muscle. *Biol Sport*. 2018;35(3):277–289. PubMed ID: 30449946 doi:10.5114/biolsport.2018.77828
35. Gollnick PD, Piehl K, Saltin B. Selective glycogen depletion pattern in human muscle fibres after exercise of varying intensity and at varying pedalling rates. *J Physiol*. 1974;241(1):45–57. PubMed ID: 4278539 doi:10.1113/jphysiol.1974.sp010639
36. Kiely J. Periodization paradigms in the 21st century: evidence-led or tradition-driven? *Int J Sports Physiol Perform*. 2012;7(3):242–250. PubMed ID: 22356774 doi:10.1123/ijspp.7.3.242
37. Matomäki P, Heinonen OJ, Nummela A, et al. Durability is improved by both low and high intensity endurance training. *Front Physiol*. 2023;14:1128111. doi:10.3389/fphys.2023.1128111