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The Effect of Different High-Intensity Periodization Models on Endurance Adaptations

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[1]Faculty of Health and Sport Sciences, University of Agder, Kristiansand, NORWAY; [2]The Norwegian Olympic Federation, Oslo, NORWAY; [3]Section for Sport Science, Lillehammer University College, Lillehammer, NORWAY; and [4]Centre for Elite Sports Research, Department of Neuroscience, Norwegian University of Science and Technology, Trondheim, NORWAY

ABSTRACT

SYLTA, Ø., E. TØNNESSEN, D. HAMMARSTRÖM, J. DANIELSEN, K. SKOVERENG, T. RAVN, B. R. RØNNESTAD, Ø, SANDBAKK and S. SEILER. The Effect of Different High-Intensity Periodization Models on Endurance Adaptations. *Med. Sci. Sports Exerc.*, Vol. 48, No. 11, pp. 2165–2174, 2016. **Purpose**: This study aimed to compare the effects of three different high-intensity training (HIT) models, balanced for total load but differing in training plan progression, on endurance adaptations. **Methods**: Sixty-three cyclists (peak oxygen uptake ($\dot{V}O_{2peak}$) 61.3 ± 5.8 $mL \cdot kg^{-1} \cdot min^{-1}$) were randomized to three training groups and instructed to follow a 12-wk training program consisting of 24 interval sessions, a high volume of low-intensity training, and laboratory testing. The increasing HIT group ($n = 23$) performed interval training as 4 × 16 min in weeks 1–4, 4 × 8 min in weeks 5–8, and 4 × 4 min in weeks 9–12. The decreasing HIT group ($n = 20$) performed interval sessions in the opposite mesocycle order as the increasing HIT group, and the mixed HIT group ($n = 20$) performed the interval prescriptions in a mixed distribution in all mesocycles. Interval sessions were prescribed as maximal session efforts and executed at mean values 4.7, 9.2, and 12.7 $mmol \cdot L^{-1}$ blood lactate in 4 × 16-, 4 × 8-, and 4 × 4-min sessions, respectively ($P < 0.001$). Pre- and postintervention, cyclists were tested for mean power during a 40-min all-out trial, peak power output during incremental testing to exhaustion, $\dot{V}O_{2peak}$, and power at 4 $mmol \cdot L^{-1}$ lactate. **Results**: All groups improved 5%–10% in mean power during a 40-min all-out trial, peak power output, and $\dot{V}O_{2peak}$ postintervention ($P < 0.05$), but no adaptation differences emerged among the three training groups ($P > 0.05$). Further, an individual response analysis indicated similar likelihood of large, moderate, or nonresponses, respectively, in response to each training group ($P > 0.05$). **Conclusions**: This study suggests that organizing different interval sessions in a specific periodized mesocycle order or in a mixed distribution during a 12-wk training period has little or no effect on training adaptation when the overall training load is the same. **Key Words:** CYCLING, ENDURANCE PERFORMANCE, LACTATE THRESHOLD, MAXIMAL OXYGEN CONSUMPTION, PEAK POWER OUTPUT, TRAINING ORGANIZATION

To maximize physiological adaptations and performance capability in elite athletes, all factors involved in the training organization need to be optimized. In endurance sports, these include the duration and intensity of individual training sessions, the frequency of training sessions, and the organizational pattern of these stimulus variables over time. Recent descriptive studies of some of the world's best endurance athletes have shown that successful athletes in cycling (14,25,35), running (1,2), and cross-country skiing (21,22,33) perform a high volume of low-intensity training (LIT) (defined as work eliciting a stable blood lactate concentration [la$^-$] of less than approximately 2 $mmol \cdot L^{-1}$) in addition to much smaller but substantial proportions of both moderate-intensity training (MIT) (2–4 $mmol \cdot L^{-1}$ blood lactate) and high-intensity training (HIT) (training above maximum lactate steady-state intensity [>4 $mmol \cdot L^{-1}$ blood lactate]) throughout the preparation period. The majority of descriptive studies present a "pyramidal" training intensity distribution (TID), with high volume of LIT, substantial MIT, and less HIT, whereas a few studies suggest athletes to adopt a "polarized" TID (reduced volume

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of MIT, somewhat higher HIT), which have been proposed to give superior endurance adaptations (27,29). However, although some evidence suggests superior responses by increased HIT in a clearly polarized TID, there is currently limited empirical data comparing different stimulus ordering approaches for the HIT component of training that is often seen as critical to maximizing adaptations.

The term training "periodization" originates primarily from older eastern European texts and is widely and rather indiscriminately used to describe and quantify the planning process of training (11). Periodization plans add training load structure, with well-defined training periods designed to stimulate specific physiological adaptations (e.g., $\dot{V}O_{2max}$) or performance qualities in a specific order presumed optimal for performance development. Such endurance training models involve the manipulation of different training sessions periodized over timescales ranging from microcycle (2–7 d), to mesocycle (3–6 wk), to macrocycle (6–12 months; including preparation, competition, and transition periods). Recent experimental findings indicate improved training adaptations after shorter, highly focused training periods of HIT compared with mixed programs with the same total quantity of intensive sessions (18–20). For example, Rønnestad et al. (18) found superior effects of a 12-wk block periodization program, where each 4-wk cycle consisted of 1 wk of five HIT sessions, followed by 3 wk of one HIT session per week, when compared with a traditional program incorporating "two weekly HIT sessions." However, others report superior effects after a polarized TID compared with an HIT block periodized training concept (28). The latter study was, however, not conducted with groups performing the same quantity of HIT sessions, which may have affected the results.

These recent findings not only confirm HIT to be an important stimulus for endurance adaptations but also highlight mesocycle organization as a potential modifier of the adaptive response. Previous research has shown that the physiological adaptations to HIT sessions are also sensitive to the interactive effects of intensity and accumulated duration. For example, both Seiler et al. (26) and Sandbakk et al. (23) have recently demonstrated that slight reductions in HIT work intensity facilitated large increases in tolerable accumulated duration and better overall adaptive responses in well-trained cyclists and cross-country skiers. Although research has progressed our understanding of the intensity/accumulated duration relationship during HIT sessions and its relationship with endurance performance development in an isolated fashion (23,26), the accumulative effects of the order of such sessions are not well understood. Different patterns of HIT ordering are used by elite athletes. Some endurance athletes increase HIT intensity and decreasing HIT duration from the preparation to the competition period (32,33). However, anecdotal evidence also shows that some successful athletes use a "reversed" model, where HIT intensity is decreased and HIT duration increased, or a "mixed" model with larger microvariation of various HIT sessions (e.g., interval sessions) throughout the training period.

Therefore, the main purpose of this study was to compare the effects of three different HIT models, balanced for total load but periodized in a specific mesocycle order or in a mixed distribution, on endurance adaptations during a 12-wk training period in well-trained endurance athletes. We simulated a preparation period in which cyclists in increasing (INC), decreasing (DEC), and mixed (MIX) HIT groups performed training periods that were matched for all features (frequency, total volume, and overall HIT load) except the mesocycle order or distribution of HIT sessions. We hypothesized that the INC HIT organization would be best tolerated and give best overall adaptive effects.

METHODS

This was a multicenter study involving three test centers completing the same controlled experimental trial. At each test center, three matched periodization groups were instructed to follow a 12-wk high-volume LIT model, in addition to a significant portion HIT performed as prescribed as supervised interval sessions. Performance and physiological tests were compared before and after the intervention period.

Subjects

Sixty-nine male cyclists (38 ± 8 yr, $\dot{V}O_{2peak}$ 62 ± 6 $mL \cdot kg^{-1} \cdot min^{-1}$) were recruited to the study using announcements in social media and through local cycling clubs. Inclusion criteria were as follows: 1) male, 2) $\dot{V}O_{2peak}$ >55 $mL \cdot kg^{-1} \cdot min^{-1}$, 3) training frequency more than four sessions per week, 4) cycling experience >3 yr, 5) regularly competing, and 6) absence of known disease or exercise limitations. Study participation was administered from three different test locations, including 29, 20, and 20 subjects, respectively. All subjects were categorized as well trained (12) or at performance level 4 according to an athlete categorization by De Pauw et al. (6). All subjects completed the intervention. However, we excluded six subjects from the final analyses because of absence from posttesting and/or <70% compliance with prescribed interval sessions. Excluded subjects were from MIX (two subjects) and DEC (four subjects) groups. The study was approved by the ethics committee of the Faculty for Health and Sport Science, University of Agder, and registered with the Norwegian Social Science Data Services. All subjects gave their verbal and written informed consent before study participation.

Preintervention Period

Before intervention, a 6-wk preintervention period (PIP) was conducted to familiarize subjects with interval sessions included in the intervention period and with testing protocols (Fig. 1). During the PIP, subjects were instructed to perform only one interval session each week, combined with freely chosen (*ad libitum*) LIT volume. All subjects completed a questionnaire regarding training history the previous year, years of cycling experience, previous peak performance level,

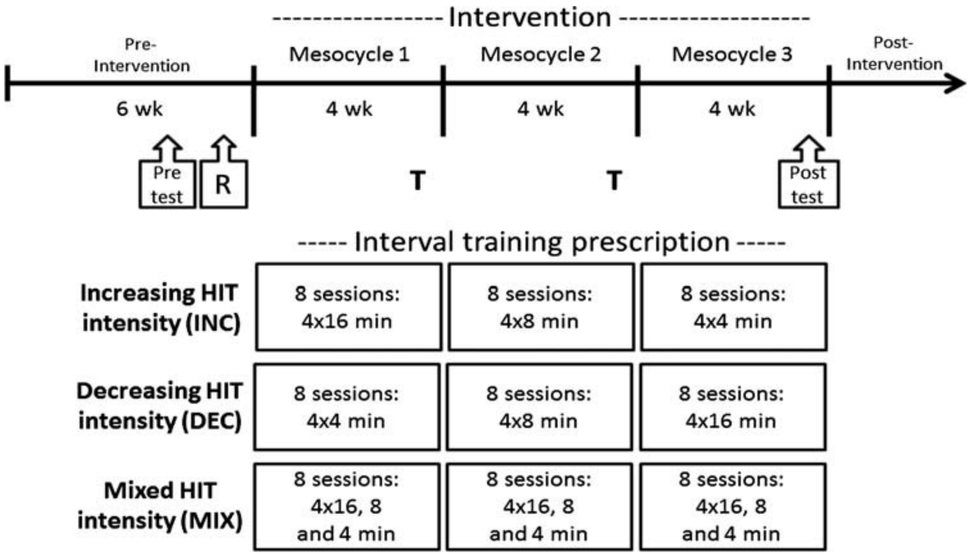

FIGURE 1—Study protocol. A 6-wk PIP, including familiarization to interval sessions, pretesting, and randomization (R), was followed by a 12-wk intervention period divided in three 4-wk mesocycles with different interval session prescriptions for each training group. All groups performed 24 supervised interval sessions, in addition to testing and *ad libitum* LIT. The INC group (n = 23) performed 8 interval sessions as 4 × 16 min in mesocycle 1 (weeks 1–4), 8 interval sessions as 4 × 8 min in mesocycle 2 (weeks 5–8), and 8 interval sessions as 4 × 4 min in mesocycle 3 (weeks 9–12). The DEC group (n = 20) performed interval sessions in the opposite mesocycle order as INC, and the MIX group (n = 20) organized all 24 interval sessions (8 in each mesocycle) in a mixed distribution; sessions 1 as 4 × 16 min, session 2 as 4 × 8 min, session 3 as 4 × 4 min, session 4 as 4 × 16 min, and so on. In total, during 12 wk, all subjects independent of group performed 8 interval sessions in each 4 × 16-, 4 × 8-, and 4 × 4-min prescriptions, respectively. All subjects were tested (T) in-between cycles during weeks 4 and 8 (results not presented). Posttesting was completed within 5 d postintervention period.

and previous/current injuries and diseases. Pretesting was performed at the end of the PIP (mid-December), and subjects were thereafter randomized into one of three different training groups (INC, DEC, and MIX) matched for 1) age, 2) cycling experience, and 3) $\dot{V}O_{2peak}$.

Intervention Period

Training organization. The training intervention was performed from early January to the end of March (12 wk), corresponding to the early preparation period for these cyclists and consisted of three 4-wk mesocycles. Subjects were instructed to follow a mesocycle week load structure as follows: week 1, medium LIT volume and two supervised interval sessions; weeks 2 and 3, high LIT volume and three supervised interval sessions; and week 4, reduced LIT volume by 50% compared with the previous 2 wk and one HIT session executed as a physiological test (results not presented). In total, each subject was prescribed 24 supervised interval sessions, in addition to laboratory testing, and self-organized *ad libitum* LIT equal to the subject's normal LIT volume. Each intervention group organized interval sessions in a specific periodized mesocycle order or in a mixed distribution during mesocycles 1–3 (Fig. 1).

Interval sessions. All HIT was performed indoors as supervised group interval training sessions and included a 20- to 30-min low-intensity (55%–70% HR_{max}) warm-up, followed by four interval bouts of 4, 8, or 16 min separated by a 2-min rest, and concluded with a 10- to 30-min low-intensity (55%–70% HR_{max}) cooldown. Sessions were performed at the same time of day throughout the intervention period with room temperature maintained at 17°C–20°C and 50%–60% relative humidity. Subjects manipulated cycling load electronically by adjusting the ergometer with ±3-W precision, and they were provided with continuous feedback regarding their absolute and average power, cadence (rpm), HR, and elapsed time on a large video screen. Revolutions per minute was individually selected. During interval sessions, subjects were instructed to cycle at their maximal sustainable intensity during all four interval bouts (isoeffort) (26,27) such that they 1) completed the described session structure (all four interval bouts completed with only a 2-min rest) and 2) with even or progressive power from first to fourth interval bout. Before each interval session, we estimated the power each subject would be able to maintain during all interval bouts based on previous interval sessions and subject feedback. Mean power, HR (mean and peak), RPE 6–20 (3), and revolutions per minute were quantified at the end of each interval lap. Blood lactate concentration [la^-] was measured randomly among a subset of 56 subjects at the end of the third and fourth interval bout. Data from all intervention groups pooled together showed that the three different interval prescriptions (4 × 16 min, 4 × 8 min, and 4 × 4 min) induced significantly different mean power, [la^-], and HR (mean and max) responses. In addition, both RPE and session RPE (sRPE) (9) were significantly different across interval prescriptions despite the same "maximal session effort" approach (Table 1). However, all intervention groups (INC, DEC, and MIX) executed the three different interval prescriptions with similar mean power, [la^-], HR (mean and

TABLE 1. Physiological and perceptual responses during interval sessions executed as 4 × 16, 4 × 8, and 4 × 4 min during a 12-wk intervention period.

	4 × 16 min	4 × 8 min	4 × 4 min	P*
Compliance (% HIT sessions)	93.1 (14.2)	96.4 (8.8)	92.5 (13.2)	0.052
Power (W)[a]	276 (25)	308 (29)	342 (33)	<0.001
Power (W·kg^{-1})[a]	3.5 (0.4)	3.9 (0.4)	4.3 (0.4)	<0.001
Percent of PPO (%)[a]	65 (4)	71 (4)	80 (4)	<0.001
Percent of 4 mM lactate power (%)[a]	97 (8)	106 (8)	118 (9)	<0.001
Blood lactate (mmol·L^{-1})[b]	4.7 (1.6)	9.2 (2.4)	12.7 (2.7)	<0.001
Interval lap HR$_{\text{mean}}$ (% HR$_{\text{peak}}$)[a]	86 (3)	88 (2)	89 (2)	<0.001
Interval lap HR$_{\text{peak}}$ (% HR$_{\text{peak}}$)[a]	89 (2)	91 (2)	94 (2)	<0.001
RPE (6–20)[a]	15.0 (1.1)	16.2 (0.8)	17.1 (0.9)	<0.001
sRPE 30 min postsession (1–10)	6.3 (1.0)	6.9 (1.0)	7.7 (1.2)	<0.001

All values are calculated as the mean (SD) of up to 24 training sessions in 63 subjects. Compliance is calculated as percent of total interval sessions executed in relation to number of described sessions (24 in each subject).

[a] All values of power, mean/peak HR, and RPE represent a mean of all four interval laps. sRPE was quantified 30 min postexercise.

[b] Blood lactate was measured randomly among a subset of 56 subjects after interval laps 3 and 4, and a total of 531 samples (~10 per participant) were collected.

*One-way repeated-measures ANOVA.

max), RPE, and sRPE. In addition, there was no significant difference in total compliance (% interval sessions completed) among intervention groups.

Training monitoring. All subjects were provided with the Norwegian Olympic committee's online training diary to record their training. The following variables were registered for each training session: 1) total training form duration (endurance, strength, sprint/jump, other), 2) activity form duration (cycling, running, cross-country skiing, etc.), 3) total duration in each endurance training zone (session goal/time in zone method [31]), 4) session goal categorical intensity distribution (31), 5) perceived exertion (1–10) rated 30 min postexercise (sRPE) (8), and 6) self-reported recovery status (1–9) (18). Individualized HR zones were calculated based on the HR$_{\text{peak}}$ results from pretesting using a five-zone aerobic intensity scale used by the Norwegian Olympic Federation to prescribe and monitor the training of well-trained endurance athletes: zone 1, 60%–75% HR$_{\text{peak}}$; zone 2, 75%–85% HR$_{\text{peak}}$; zone 3, 85%–90% HR$_{\text{peak}}$; zone 4, 90%–95% HR$_{\text{peak}}$; and zone 5, 95%–100% HR$_{\text{peak}}$ (27).

There were no significant differences among groups in any training variable measured as mean during 12 wk (Table 2) and no significant differences in training volume during the intervention period compared with the previous training year. Weekly training volume remained stable across mesocycles 1–3 in all groups (average cycle 1: 9.8 ± 3.2 h·wk^{-1}; cycle 2: 10.0 ± 3.2 h·wk^{-1}; cycle 3: 10.7 ± 3.1 h·wk^{-1}). A self-reported scale for recovery status suggested that subjects were fully recovered every fourth week, as there were no significant differences among the three intervention groups or across 4-wk training cycles in self-reported recovery status (data not shown).

Testing Procedures

Pretesting was completed 2 wk before intervention start. Posttesting was initiated 2–4 d after the last supervised interval session for all subjects and completed within 10 d. Both testing periods were performed for 2 d separated by a minimum of 48 h recovery. Subjects were instructed to perform only LIT for a minimum of 48 h preceding each test and to consume the same type of meal. They were instructed to not eat during the last hour or consume caffeine during the last 3 h preceding testing.

Test day 1. On day 1, four to six submaximal incremental 5-min steps were performed in the laboratory on a bicycle ergometer to identify the workload eliciting 4 mmol·L^{-1} [la$^-$] (Power$_{4\text{mM}}$) and gross efficiency (GE). The test started with 5-min cycling at 125 W, and $\dot{V}O_2$, respiratory exchange ratio (RER), and HR were measured during the last 2.5 min, with mean values for this period used for statistical analyses. Blood [la$^-$] was measured after 4.30 min, and RPE was determined at the end of each 5-min step using Borg's 6–20 RPE scale (3). Power was increased by 50 W (25 W if [la$^-$] was >3 mmol·L^{-1}) after 5 min. Testing was terminated when [la$^-$] reached ≥4 mmol·L^{-1}. Power and $\dot{V}O_2$ corresponding to

TABLE 2. Weekly training characteristics and sickness during a 12-wk training period in 63 subjects, randomized to INC, DEC, and MIX training groups.

	All (N = 63)	INC (n = 23)	DEC (n = 20)	MIX (n = 20)	P*
Training volume (h·wk^{-1})	10.1 (2.9)	10.8 (2.6)	9.9 (3.1)	9.6 (2.9)	0.354
Training forms					
Endurance (%)	96.9 (3.7)	97.2 (4.2)	96.6 (3.3)	97.0 (3.7)	0.883
Strength (%)	2.6 (3.5)	2.3 (4.1)	2.7 (3.2)	2.7 (3.1)	0.928
Speed/jumps (%)	0.1 (0.3)	0.0 (0.1)	0.2 (0.4)	0.0 (0.1)	0.198
Other (%)	0.4 (0.9)	0.4 (0.9)	0.5 (0.9)	0.3 (0.8)	0.799
Intensity distribution					
Zone 1 (%)	71.2 (13.7)	72.8 (12.5)	67.7 (15.0)	72.8 (13.7)	0.397
Zone 2 (%)	12.3 (9.0)	11.6 (8.3)	15.9 (9.8)	9.4 (8.1)	0.063
Zone 3 (%)	8.9 (3.8)	9.0 (3.5)	8.4 (3.5)	9.4 (4.6)	0.693
Zone 4 (%)	5.3 (2.5)	4.7 (1.8)	5.3 (2.5)	5.9 (3.0)	0.290
Zone 5 (%)	2.3 (1.4)	1.9 (1.0)	2.7 (1.5)	2.5 (1.7)	0.201
Specific training (%)	81.3 (15.1)	78.0 (17.8)	84.0 (14.0)	82.5 (12.6)	0.408
Sickness (d)	3.8 (3.6)	3.1 (2.4)	3.1 (3.1)	5.2 (4.7)	0.106

Values are presented as mean (SD). Intensity distribution and specific training are calculated as percent of endurance training, and distributed according to session goal/time in zone-method (SG/TIZ) (33). Zone 1 = 60%–75% of HR$_{\text{peak}}$; zone 2 = 75%–85% of HR$_{\text{peak}}$; zone 3 = 85%–90% of HR$_{\text{peak}}$; zone 4 = 90%–95% of HR$_{\text{peak}}$; zone 5 = 95%–100% of HR$_{\text{peak}}$.

*One-way between-groups ANOVA.

4 mmol·L^{-1} [la^{-}] were identified after plotting the true power–lactate curve for each subject, by fitting a polynomial regression model (17). GE was calculated using the method of Coyle et al. (5). Briefly, the rate of energy expenditure was calculated by using gross $\dot{V}O_2$ from the first three 5-min submaximal steps (125, 175, and 225 W), and GE was expressed as the ratio of work accomplished per minute to caloric expenditure per minute.

After 10 min recovery, an incremental test to exhaustion was performed to determine 1) $\dot{V}O_{2peak}$, 2) peak power output (PPO), 3) HR_{peak}, and 4) peak blood lactate concentration [la^{-} $_{peak}$]. The test started with 1 min of cycling at 3 W·kg^{-1} (rounded down to nearest 50 W) and subsequently increased by 25 W every minute until voluntary exhaustion or failure to maintain ≥70 rpm. Strong verbal encouragement was provided throughout the test. $\dot{V}O_{2peak}$ was calculated as the average of the two highest 30-s consecutive $\dot{V}O_2$ measurements. The plateau of the $\dot{V}O_2$ curve and/or the HR ≥95% of known HR_{max}, RER ≥1.10, and [la^{-}] ≥8.0 mmol·L^{-1} were used as criteria for the attainment of a valid test (10). PPO was calculated as the mean power during the last minute of the test. HR_{peak} was recorded during the final 5 s before exhaustion, and [la$^{-}_{peak}$] was measured 60 s postexhaustion. In addition, a theoretical maximal aerobic power was calculated by using submaximal $\dot{V}O_2$ measurements in addition to $\dot{V}O_{2peak}$. Maximal aerobic power was defined as the power where the horizontal line representing $\dot{V}O_{2peak}$ meets the extrapolated linear regression representing the submaximal $\dot{V}O_2$/power relationship. To estimate fractional use of $\dot{V}O_{2peak}$, the previously described $\dot{V}O_2$ corresponding to 4 mmol·L^{-1} [la^{-}] was calculated as percentage of $\dot{V}O_{2peak}$ (%$\dot{V}O_{2peak}$@4 mM).

Finally, after 15 min recovery, a 30-s all-out Wingate test (36) was conducted. The test started with the subject pedaling at a freely chosen cadence less than 120 rpm for 20 s with an ~150-W braking resistance. Then after a 3-s countdown, a braking resistance equivalent to 0.7 N·m·kg^{-1} body mass (Lode Excalibur) or a 0.098 torque factor (Velotron) was applied to the flywheel and remained constant throughout the 30-s test. Cyclists were instructed to pedal as fast as possible from start and were allowed to sit or stand as preferred throughout the test. Strong verbal encouragement was provided throughout. The mean power during 30 s ($Power_{30s}$) was recorded.

Test day 2. On test day 2, subjects performed a 40-min all-out trial. The test started with a 30-min warm-up at a self-selected power output. Thereafter, subjects were instructed to cycle at the highest possible mean power during 40 min. Subjects were blinded to power output and HR but were allowed to see remaining time and rpm. They were encouraged to remain seated during the trial but were permitted to stand and stretch their legs occasionally, and they were allowed to drink water *ad libitum*. Mean power, mean HR (HR_{mean}), and HR_{peak} were registered, as well as RPE and [la^{-}], at the end of the test.

Instruments and materials. For each individual, all tests on day 1 were performed on the same Velotron (Racermate, Seattle, WA) or Lode Excalibur Sport (Lode B. V., Groningen, The Netherlands) cycle ergometer under similar environmental conditions (18°C–22°C/50%–60% relative humidity). Pre- and posttests were performed at the same time of day. Saddle height, handlebar position, and distance between the tip of the saddle and the bottom bracket were adjusted by each subject as desired. Subjects were instructed to remain seated during all tests (except the 30-s all-out test) and allowed to choose their preferred cadence. Both test ergometers are computer controlled and provide <2% margin of error in both accuracy and repeatability, according to the manufacturer. Test day 2 and all interval sessions were performed in groups on their own road racing bicycle mounted on Computrainer Lab^{TM} ergometers (Race Mate, Seattle, WA) calibrated according to the manufacturer's specifications and connected to a central PC running dedicated software (PerfPRO Studio, Hartware Technologies, Rockford, MI).

$\dot{V}O_2$ was measured using Oxycon Pro™ with a mixing chamber and a 30-s sampling time (Oxycon; Jaeger GmbH, Hoechberg, Germany). Gas sensors were calibrated via an automated process using certified calibration gasses of known concentrations before every test. The flow turbine (Triple V, Erich Jaeger) was calibrated using a 3-L calibration syringe (5530 series; Hans Rudolph, Kansas, MO). HR was measured using Polar V800 (Polar Elektro Oy, Kempele, Finland). Blood [la^{-}] were analyzed using a stationary lactate analyzer (EKF BIOSEN; EKF Diagnostics, Cardiff, UK).

Statistical Analyses

Data were analyzed using SPSS 22.0 (SPSS Inc., Chicago, IL) and are presented as mean ± SD or 95% confidence intervals (95% CI). Baseline and training characteristics were compared using a one-way between-groups ANOVA, followed by Bonferroni-corrected *post hoc* tests. A one-way repeated-measures ANOVA was used to compare differences among 4 × 16 min, 4 × 8 min, and 4 × 4 min interval session prescriptions. A univariate general linear model (GLM) (ANCOVA) was used to assess differences in baseline characteristics and changes in test variables among the intervention groups. A GLM repeated-measures model (ANOVA) was used to compare pre- and posttest results in each group. GLM analyses were adjusted for the influence of different covariates (test location and pre-$Power_{4mM}$ (W·kg^{-1})) and conducted to ensure that there were no violations of the assumptions of normality, linearity, and sphericity. All data analyzed by GLM are presented as adjusted values. Because of expectations of small changes in these already well-trained cyclists, the data were further analyzed with effect size (ES) calculated according to Cohen's *d* (0.2 = small, 0.5 = medium, 0.8 = large) (4). Medium or large ES (>0.5) are discussed as tendencies if comparisons are nonsignificant. The frequency distribution of individual response magnitude across training groups was compared using a chi-square test, and ES was calculated with Cramer's *V* with three categories (4). For all comparisons, statistical significance was accepted as $\alpha \leq 0.05$.

RESULTS

Baseline Characteristics and Body Mass

There were no significant differences among training groups before the intervention period with respect to age, cycling experience, body mass, or any performance or physiological test variables (Table 3). After the intervention, there was a significant body mass reduction in INC (80.3 ± 7.4 vs 79.0 ± 7.6 kg), DEC (79.7 ± 7.8 vs 78.5 ± 7.5 kg), and MIX (79.7 ± 8.9 vs 78.2 ± 8.8 kg) training groups (all $P < 0.05$).

Performance Responses

All training groups improved significantly in all performance measures after the intervention period. The mean (95% CI) improvement before and after the mean power during a 40-min all-out trial ($\text{Power}_{40\text{min}}$) was 8.0% (5.3–10.6), 7.4% (4.4–10.4), and 4.9% (1.8–8.0) in INC, DEC, and MIX groups, respectively (all $P < 0.05$; Fig. 2). The relative improvement did not differ among groups ($P = 0.307$), but there was a medium ES when comparing difference in absolute values (Table 3) in INC and DEC versus MIX groups. Mean (95% CI) PPO values increased significantly by 7.1% (4.7–9.5), 6.0% (3.4–8.6), and 6.5% (3.9–9.2) in INC, DEC, and MIX groups, respectively (all $P < 0.05$; Fig. 2), with no differences among groups ($P = 0.813$). The MIX and the DEC groups improved significantly in mean (95% CI) $\text{Power}_{30\text{s}}$ by 2.4% (0.3–4.4) and 2.7% (0.7–4.7), respectively (both $P < 0.05$), whereas a nonsignificant 1.2% (−0.7, 3.1) change occurred in the INC group. The changes in $\text{Power}_{30\text{s}}$ did not differ among groups ($P = 0.509$).

Physiological Responses

The INC and the DEC groups improved mean (95% CI) $\text{Power}_{4\text{mM}}$ significantly by 5.8% (2.7–8.9) and 5.9% (2.6–9.2), respectively (all $P < 0.05$).The MIX group showed a nonsignificant change of 2.9% (−0.4 to 6.3) (Fig. 2). The relative changes among groups in $\text{Power}_{4\text{mM}}$ did not differ ($P = 0.360$), but there was a medium ES when comparing absolute values (Table 3) in the INC group versus the MIX group. All groups significantly improved mean (95% CI) $\dot{V}O_{2\text{peak}}$ by 5.8% (3.7–8.0), 4.5% (2.3–6.8), and 3.8% (1.5–6.0) in the INC, DEC, and MIX groups, respectively (all $P < 0.05$; Fig. 2). No significant differences occurred among groups ($P = 0.392$), but there was a medium ES when comparing absolute values (Table 3) in the INC group versus the MIX group.

The DEC group significantly improved mean (95% CI) fractional use calculated as $\dot{V}O_{2\text{peak}}$@4 mM by 3.7% (1.2–6.3) ($P < 0.05$). There was a nonsignificant 1.3% (−1.1 to 3.7) and −0.5% (−3.1 to 2.1) change in the INC and MIX groups,

TABLE 3. PRE values and PRE to POST changes in performance and physiological variables during a 12-wk training period with different periodization models in INC, DEC, and MIX training groups.

	All Groups (N = 63)		INC (n = 23)		DEC (n = 20)		MIX (n = 20)		Among Groups—Relative Change	
	Mean PRE (95% CI)	Mean change (95% CI)	Mean PRE (95% CI)	Mean change (95% CI)	Mean PRE (95% CI)	Mean change (95% CI)	Mean PRE (95% CI)	Mean change (95% CI)	P^a	ES^b INC/DEC vs MIX
Body composition										
Body mass (kg)	79.7 (77.9 to 81.5)	−1.3* (−1.7 to −0.9)	80.3 (76.9 to 83.6)	−1.3* (−1.9 to −0.7)	79.5 (76.6 to 82.4)	−1.2* (−2.1 to −0.4)	79.4 (75.6 to 83.2)	−1.6* (−2.4 to −0.8)	0.809	−0.2/−0.2
Performance										
$\text{Power}_{40\text{min}}$ (W)	281 (274 to 288)	19* (14 to 23)	281 (267 to 295)	23* (14 to 32)	279 (269 to 289)	19* (10 to 27)	287 (275 to 299)	10* (4 to 16)	0.267	0.8/0.6
PPO (W)	413 (406 to 421)	26* (20 to 31)	416 (400 to 431)	30* (19 to 41)	414 (400 to 427)	22* (14 to 31)	413 (400 to 426)	25* (12 to 37)	0.796	0.2/−0.1
Aerobic										
$\text{Power}_{4\text{mM}}$ (W)	281 (275 to 288)	13* (8 to 18)	276 (265 to 287)	17* (6 to 28)	283 (273 to 292)	14* (7 to 22)	286 (272 to 300)	6 (−5 to 16)	0.441	0.5/0.4
$\dot{V}O_{2\text{peak}}$ ($\text{mL}\cdot\text{min}^{-1}$)	4858 (4742 to 4974)	226* (163 to 288)	4941 (4736 to 5146)	299* (191 to 407)	4793 (4585 to 5002)	197* (103 to 290)	4859 (4631 to 5088)	140* (4 to 276)	0.356	0.6/0.2
$\dot{V}O_{2\text{peak}}$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	61.3 (60.1 to 62.4)	3.9* (3.1 to 4.7)	61.8 (59.5 to 64.1)	4.8* (3.5 to 6.1)	60.6 (58.7 to 62.5)	3.5* (2.0 to 5.0)	61.6 (59.8 to 63.4)	3.0* (1.3 to 4.7)	0.384	0.6/0.2
MAP (W)	371 (362 to 381)	12* (6 to 19)	376 (361 to 390)	19* (6 to 32)	372 (355 to 388)	3 (−8 to 15)	369 (348 to 390)	12 (0 to 25)	0.332	0.3/-0.4
% $\dot{V}O_{2\text{peak}}$@4 mM (%)	79.2 (77.9 to 80.4)	1.1 (−0.1 to 2.3)	77.3 (74.7 to 80.0)	0.7 (−1.4 to 2.8)	79.4 (77.3 to 81.5)	2.8* (0.6 to 5.1)	80.7 (78.7 to 82.7)	−0.4 (−2.5 to 1.7)	0.090	0.2/0.7
GE (%)	19.0 (18.8 to 19.3)	−0.4* (−0.6 to −0.2)	18.8 (18.4 to 19.3)	−0.5* (−0.9 to −0.2)	19.3 (18.9 to 19.7)	−0.4* (−0.7 to −0.1)	19.1 (18.7 to 19.5)	−0.2 (−0.7 to 0.2)	0.669	0.3/0.3
Anaerobic										
$\text{Power}_{30\text{s}}$ (W)	826 (809 to 842)	16* (7 to 25)	849 (825 to 873)	10 (−6 to 26)	820 (789 to 851)	20* (3 to 36)	812 (778 to 845)	18* (1 to 36)	0.535	−0.2/0.1

All values are presented as mean (95% CI). $\text{Power}_{40\text{min}}$, mean power during 40-min all-out trial; $\text{Power}_{4\text{mM}}$, power corresponding to 4 $\text{mmol}\cdot\text{L}^{-1}$ lactate; $\dot{V}O_{2\text{peak}}$, peak oxygen uptake; %$\dot{V}O_{2\text{peak}}$@4 mM, percent peak oxygen uptake corresponding to 4 $\text{mmol}\cdot\text{L}^{-1}$ lactate; Power30s, mean power during 30 s all-out test; MAP, maximal aerobic power.

[a] General linear model univariate, adjusted for test location and prepower at 4 $\text{mmol}\cdot\text{L}^{-1}$ lactate ($\text{W}\cdot\text{kg}^{-1}$).

[b] ES calculations according to Cohen's d (0.2 = small, 0.5 = medium, 0.8 = large) (4).

*$P < 0.05$ PRE vs POST within group.

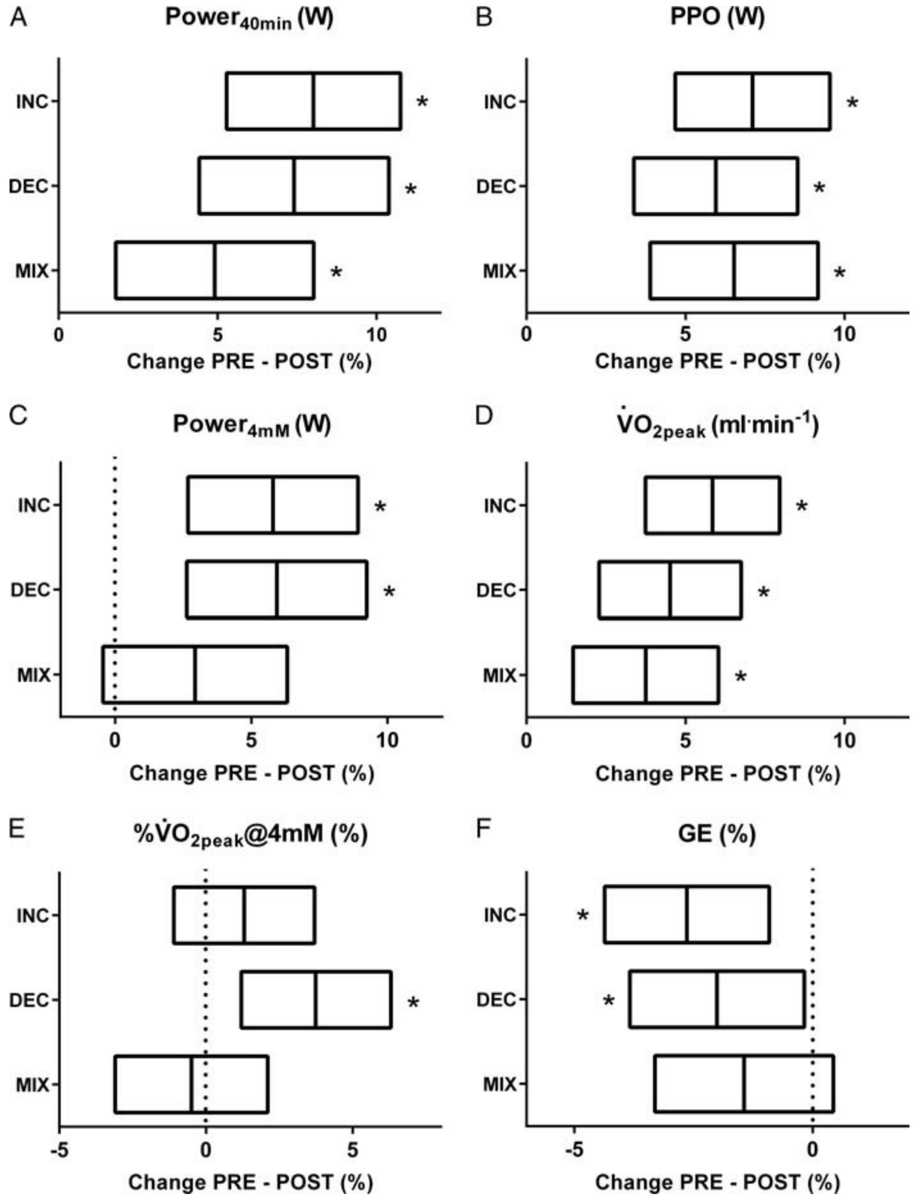

FIGURE 2—The 95% CI for relative change after a 12-wk training period (PRE–POST) in $\text{Power}_{40\text{min}}$ (A), PPO (B), $\text{Power}_{4\text{mM}}$ (C), $\dot{V}O_{2\text{peak}}$ (D), %$\dot{V}O_{2\text{peak}}$@4 mM (E), and GE (F), in INC ($n = 23$), DEC ($n = 20$), and MIX ($n = 20$) intervention groups. $\text{Power}_{40\text{min}}$, mean power during a 40-min all-out trial; $\text{Power}_{4\text{mM}}$, power corresponding to 4 mmol·L^{-1} lactate; $\dot{V}O_{2\text{peak}}$ = peak oxygen uptake; %$\dot{V}O_{2\text{peak}}$@4 mM, percent peak oxygen uptake corresponding to 4 mmol·L^{-1} lactate.

respectively (Fig. 2). Although the relative changes among groups did not differ ($P = 0.070$), there was a medium ES when comparing the DEC group versus the MIX group. All groups decreased in GE. Mean (95% CI) relative changes were −2.6% (−4.4 to −0.9) in the INC group ($P < 0.05$), −2.0% (−3.8 to −0.2) in the DEC group ($P < 0.05$), and −1.4% (−3.3 to 0.4) in the MIX group (not significant) (Fig. 2), with no significant differences among groups ($P = 0.642$).

A chi-square test for independence indicated no significant association among training groups and individual performance ($\text{Power}_{40\text{min}}$) response ($P = 0.146$, Fig. 3). There was, however, a medium ES (4), calculated with Cramer's V with three categories. Approximately 87%, 63%, and 56% of subjects in the INC, DEC, and MIX groups, respectively, achieved moderate to large gains in performance capacity, whereas ~13%, 37%, and 44% showed nonresponse.

DISCUSSION

The present study demonstrates that, at the group level, the physiological and performance improvements after intensified training were moderate to large in all the training groups used in this study. This indicates that the basic load features of the training were well tolerated and effective. However, the specific HIT periodized mesocycle order or mixed distribution, focusing on manipulating the intensity prescription for interval sessions, had little or no generalizable effect on the adaptive effect of the same overall

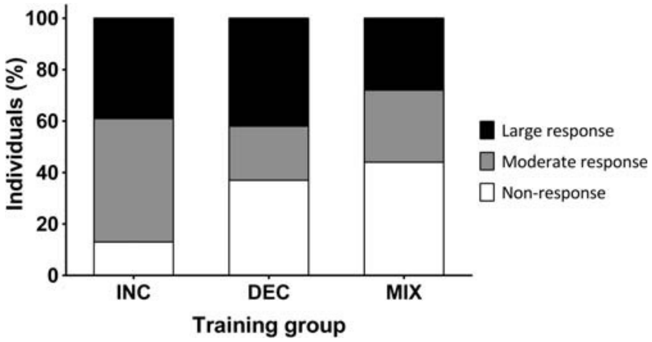

FIGURE 3—Individual response distribution to PRE–POST change (%) in performance (mean power during 40-min all-out trial) after a 12-wk training in INC (*n* = 23), DEC (*n* = 19), and MIX (*n* = 18) intervention groups. Percent change was categorized as nonresponse, <3% change; moderate response, 3%–9% change; or large response, >9% change.

endurance training load. Furthermore, the individual variation in training response did not significantly differ among the three training groups, suggesting similar expected distribution of large, moderate, or nonresponses, respectively, to each prescription.

Performance and Physiological Adaptations

After a 12-wk training period, including two to three interval sessions each week in addition to *ad libitum* LIT, we found that all groups significantly increased performance variables (Power$_{40min}$ and PPO) by 5%–8%. Coinciding with 40-min all-out trial improvements, Power$_{4mM}$ also increased by 3%–6% in all groups. These performance response magnitudes are consistent with previous studies investigating the effect of HIT over similar time frames (15,18,24), or after shorter HIT interventions (2%–6% improvement) (12,30). Furthermore, all groups increased $\dot{V}O_{2peak}$ significantly by 4%–6%, which is in line with the increase in $\dot{V}O_{2max}$ reported in other studies involving well-trained to elite-level cyclists during comparable training periods (15,18,24). Overall, our results demonstrate that the training load prescribed in the present study was effective in improving performance and physiological capacity in well-trained cyclists.

We found negligible changes in the fractional use of $\dot{V}O_{2peak}$ from pre- to posttest, in both the INC (~1%) and the MIX (~0%) groups. The overall small changes in this variable are likely because short-term HIT stimuli are more effective in inducing central cardiovascular adaptations (13). However, the DEC group improved by ~4%.

A small decrease in GE occurred in all groups, despite increased $\dot{V}O_{2peak}$. A relative shift in energetic contribution from carbohydrate to fat could account for a small decrease in GE. For example, a shift in RER from 0.87 to 0.82 at the same oxygen consumption and power output would result in an ~1% decline in GE (from for example, 21.6%–21.4%). However, the decrease in GE observed in the present study was still larger than what could be explained by a shift in RER toward greater fat use. The main contributor to decreased GE is therefore probably due to higher oxygen consumption, which has also been reported previously (9).

Group Comparisons

Despite large overall progress in all groups, we found no significant differences among groups in adaptive changes from pre- to postintervention, except the fractional use of $\dot{V}O_{2peak}$ where the DEC group tended to improve more than the other groups. The latter may be a compensation of the slightly smaller increase in $\dot{V}O_{2peak}$ in DEC compared with the INC group. Altogether, these results suggest that organizing different interval sessions in a specific periodized "increasing" or "decreasing" mesocycle order or in a mixed intensity distribution results in minor differences in adaptive response when the overall load is the same.

However, although there were no significant differences among groups, the greater microvariation of interval training stimuli (i.e., the MIX group) tended to induce less overall adaptive responses compared with the INC and the DEC groups. We speculate that this tendency could be explained by higher interval session "quality" in the INC and DEC groups who, unlike the MIX group, performed the same eight interval sessions consecutively during each mesocycle. Therefore, subjects in the INC and DEC groups may have been more familiar with their specific sessions and, thus, able to more accurately pace their tolerable power/intensity from the beginning of the first to the end of the fourth interval bout.

We have failed to find any experimental studies for direct comparisons with our results. However, previous experimental studies manipulating HIT organization patterns during timeframes from 2 to 12 wk indicate improved block periodization training adaptations compared with mixed programs (18–20) and superior effects after a polarized TID compared with an HIT block periodization training concept (28). However, in these studies, block periodization was organized as short periods with heavy HIT stimulus followed by periods with LIT focus, or without same total training load among groups, and is therefore not directly comparable to the present study.

Individual Differences in Adaptations Response

Despite excellent overall control of the training program variables, and no differences among groups in overall training load, we quantified large individual differences in adaptive response after 12 wk of training. This finding is consistent with other recent studies (16,34). Furthermore, a response distribution analysis for Power$_{40min}$ revealed no significant differences in the variability of response across groups (Fig. 3). However, we do note that only 56% and 63% of subjects in the MIX and DEC groups achieved >3% improvement, as compared with 87% of subjects in the INC group. Supplementary analyses of variables influencing the individual effects following different periodization models are needed in future studies.

Methodological Considerations

The main strengths of this study were the structured randomized design, rigorous monitoring of all training variables, and the large group of well-trained endurance athletes. We managed to match the groups for total work (isoenergetic), and all subjects, regardless of group, performed a well-documented training model with two to three weekly interval sessions interspersed with *ad libitum* LIT. On the basis of previous studies using the same model of interval training prescription (26), we anticipated that the different interval duration prescriptions (4 × 16, 8, and 4 min) would constrain three reasonably discrete work intensities, which would allow us to compare the effects on endurance adaptations when organizing those interval training prescriptions in different periodized mesocycle groups. The distinctive physiological responses to the three interval prescriptions were confirmed by the significant differences in power, [la$^-$], HR, RPE, and sRPE during interval sessions.

This study was conducted as a multicenter trial involving three test locations, which administrated 29, 20, and 20 subjects each, respectively. We are conscious that, despite our best efforts to standardize them, there could be small methodological differences across centers that may affect the intervention results.

CONCLUSIONS

The present study suggests that organizing different interval sessions in a specific periodized mesocycle order or in a mixed distribution during a 12-wk training period has little or no effect on training adaptation when the overall training load is the same. Although we found a small tendency indicating that a larger microvariation in interval training intensity and duration (i.e., the MIX group) actually induces less adaptation, we overall argue that rigid periodization structures are not supported by the results of this direct intervention study.

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None of the authors have any relevant conflicts of interest. All were involved in designing the study and writing the manuscript and/or acquisition and interpretation of data. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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