Open Access Journal of Sports Medicine

Dovepress
open access to scientific and medical research

Open Access Full Text Article

REVIEW

Block periodization of endurance training – a systematic review and meta-analysis

This article was published in the following Dove Press journal:
Open Access Journal of Sports Medicine

Knut Sindre Mølmen*
Sjur Johansen Øfsteng*
Bent R Rønnestad

Section for Health and Exercise Physiology, Inland Norway University of Applied Sciences, Lillehammer, Norway

*These authors contributed equally to this work

Background: Block periodization (BP) has been proposed as an alternative to traditional (TRAD) organization of the annual training plan for endurance athletes.
Objective: To our knowledge, this is the first meta-analysis to evaluate the effect BP of endurance training on endurance performance and factors determinative for endurance performance in trained- to well-trained athletes.
Methods: The PubMed, SPORTdiscus and Web of Science databases were searched from inception to August 2019. Studies were included if the following criteria were met: 1) the study examined a block-periodized endurance training intervention; 2) the study had a one-, two or multiple group-, crossover- or case-study design; 3) the study assessed at least one key endurance variable before and after the intervention period. A total of 2905 studies were screened, where 20 records met the eligibility criteria. Methodological quality for each study was assessed using the PEDro scale. Six studies were pooled to perform meta-analysis for maximal oxygen uptake (VO_2max) and maximal power output (Wmax) during an incremental exercise test to exhaustion. Due to a lower number of studies and heterogenous measurements, other performance measures were systematically reviewed.
Results: The meta-analyses revealed small favorable effects for BP compared to TRAD regarding changes in VO_2max (standardized mean difference, 0.40; 95% CI=0.02, 0.79) and Wmax (standardized mean difference, 0.28; 95% CI=0.01, 0.54). For changes in endurance performance and workload at different exercise thresholds BP generally revealed moderate- to large-effect sizes compared to TRAD.
Conclusion: BP is an adequate, alternative training strategy to TRAD as evidenced by superior training effects on VO_2max and Wmax in athletes. The reviewed studies show promising effects for BP of endurance training; however, these results must be considered with some caution due to small studies with generally low methodological quality (mean PEDro score =3.7/10).
Keywords: block training, traditional training, high-intensity training

Introduction

Historically, the block periodization (BP) training approach appeared for the first time in the early 1980s and has since then been popular and widely used among high-performance coaches.[1] BP was at that time and even today, an alternative to traditional periodization (TRAD). TRAD is simultaneously developing different training abilities throughout the annual training season, where BP has highly concentrated training blocks targeting and developing selected abilities in sequences of 1–4 weeks.[1,2] The BP approach was conceptualized to overcome the suggested limitations of TRAD, which has been criticized for conflicting physiological responses to multi-targeted training, resulting in 1) excessive fatigue, 2)

Correspondence: Sjur Johansen Øfsteng
Section for Health and Exercise Physiology, Inland Norway University of Applied Sciences, Postbox 400, Elverum 2418, Norway
Email sjur.johansen.ofsteng@inn.no

submit your manuscript | www.dovepress.com
DovePress
http://doi.org/10.2147/OAJSM.S180408

insufficient training stimulation and 3) inability to provide multi-peak performances over the season.[1,3] However, the effectiveness of BP and its methodological theories have also been criticized for not being sufficiently founded in empirical research literature.[4–6]

Several successful examples of BP training have been proposed during the last decades, with the first English written report, a single-case study, published in the mid-1990s.[7] However, the first English written studies comparing BP and TRAD were not published before the year 2010.[8,9] Subsequently, several studies have been published and with the growing literature in the field, there is a need to evaluate the current pooled evidence for the effect of BP of endurance training in trained athletes. Vladimir Issurin, one of the pioneers fronting BP training, states that BP has taken different forms according to the positions and experiences of those who presented them.[10] He himself defines BP training as 2–4 week mesocycles with highly concentrated workloads directed at targeted training abilities, carried out in a specific order ("accumulation", focusing on basic abilities; "transmutation", focusing on sport-specific abilities; "realization"; focusing on recovery and peaking toward competition).[10] Each of these blocks will then build off the physiological adaptations of the prior training block. On the other hand, others define shorter training blocks (~1 week, ie, microcycles) as BP training and have generally a slightly different approach to the concept.[11,12] The main difference between Issurin's and the alternative BP model is that, roughly speaking, Issurin focuses on concurrently developing a small selection of abilities in each mesocycle. In contrast to Issurin's model has the alternative model a more unidirectional focus on one specific ability in each microcycle, which has similarities to the model introduced by Professor Verkhoshansky in the 1970s.[13]

In this paper, we define BP training as either one or more blocks with ≥1 week duration of concentrated training focus with either a uni- or multitargeted approach, which means that both BP models are included. The purpose of this paper was therefore to: 1) systematically evaluate the current evidence for the effect BP of endurance training has on endurance performance and factors determinative for endurance performance in trained- to well-trained athletes; 2) conduct meta-analyses to pool and evaluate the existing effects and 3) to address the methodological quality, strengths and limitations of the current literature on this topic. To our knowledge, this is the first published meta-analysis to evaluate the effect of BP of endurance training.

Methods

Literature search

This systematic review and meta-analysis followed the guidelines established by the PRISMA statement,[14] except for the descriptive results from the literature search which in this paper is mentioned in this chapter (ie, optimized PRISMA).

A PubMed, SPORTdiscus and Web of Science literature search from inception to August 6, 2019, was conducted. The search terms included "periodization" OR "periodized" OR "periodisation" OR "periodised" OR "block" OR "blocked" OR "blocking" AND "training" OR "exercise" AND "endurance" OR "concurrent" OR "traditional". Two independent observers reviewed the studies and then individually decided whether inclusion was appropriate. Results were compared, discrepancies between reviewers were discussed and a consensus-based decision was taken. A flowchart of the search strategy and study selection is shown in Figure 1. Two independent reviewers assessed the methodological quality and risk of bias for each study using the PEDro scale from 1 to 10. Studies with scores >6 were considered "high-quality", studies with scores 4–5 were considered to be "medium-quality" and studies that scored below 4 were considered to be "low-quality".[15]

Studies were included in the review with the following criteria: 1) the study examined a BP of endurance training intervention; 2) the study had a one-, two or multiple group-, crossover- or case-study design; 3) the study assessed at least one key endurance variable or factor before and after the intervention period.

Data extraction

We extracted the following characteristics from each eligible trial: authors; year of publication; groups; training status; sample size; sex; mean baseline age and body weight; exercise modality; training period and frequency; training session protocol including work intensity and duration; if sessions were supervised or not. If applicable, the following variables with mean and variance measures were retrieved for baseline-, post- and change-values: maximal oxygen uptake (VO_2max; $mL{\cdot}min^{-1}{\cdot}kg^{-1}$) and maximal power output (Wmax) during an incremental exercise test to volitional exhaustion; workloads at

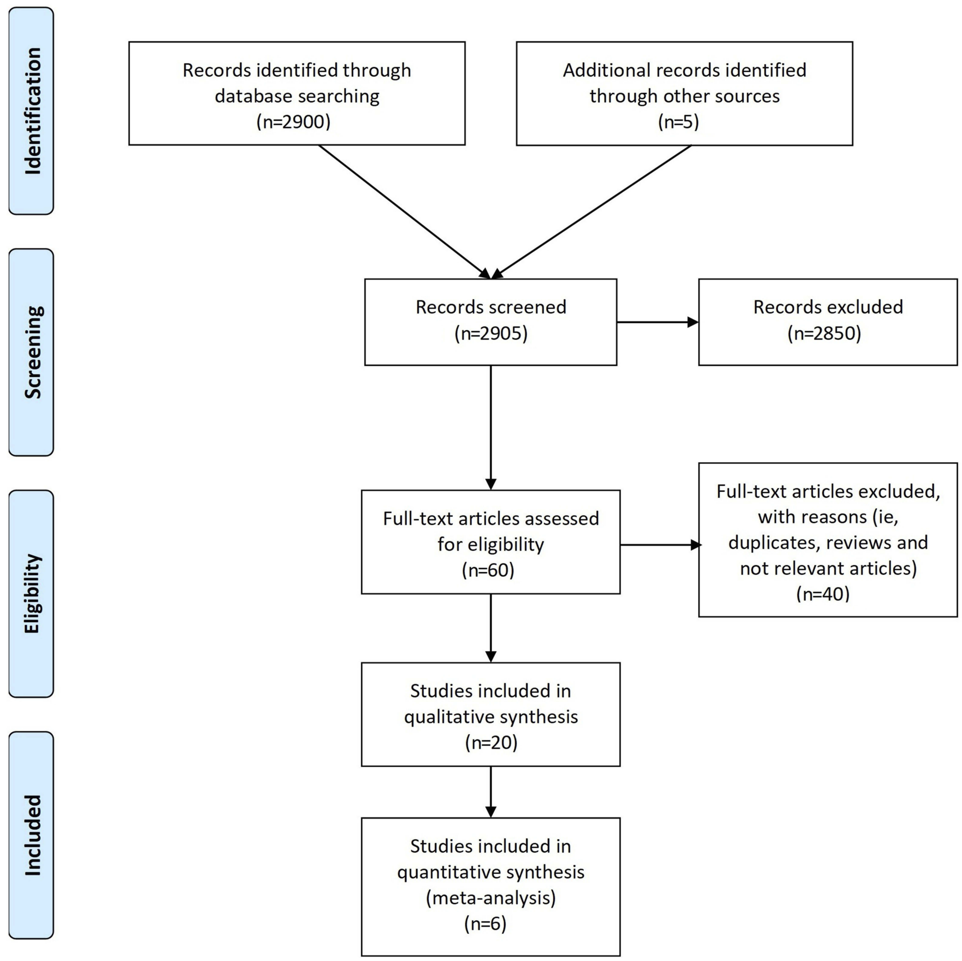

Figure 1 Flowchart of the search strategy and study selection.

different exercise thresholds (workload at second ventilatory threshold, onset of blood lactate accumulation or 2, 3 or 4 mmol·L^{-1} capillary lactate concentration); work economy; gross efficiency; endurance performance variables (closed-end tests, time to exhaustion-tests, Yo-Yo-tests). For data only described in figures or graphs, we used Fiji software[16] to read the data. Some of the data were obtained through personal contact with the authors.

Results from database search

The database search identified 2900 potentially relevant journal articles (Figure 1). Five studies were additionally included and identified through contact with the study authors, resulting in a total of 2905 records. Screening of titles and abstracts for inclusion criteria revealed 60 eligible articles for full-text review. Of these, a total of 20 records were included in this study.

The 20 studies in this review were published between the years 1993–2019. Characteristics of studies, participants and training interventions are summarized in Table 1. One of the included studies had a three groups-comparison design (1 week intervention),[17] six had a two groups-comparison design (5.8±3.8 weeks intervention, range: 1.6–12 weeks),[8,18–22] five had a one group-design (47.3±74.0 weeks intervention, range: 1.9–176 weeks),[23–27] three were crossover studies (12.0±7.8 weeks intervention, range: 3–17 weeks)[9,12,28] and five were case-studies (26.2±27.1 weeks intervention, range: 1–58 weeks).[7,29–32]

Six of the 20 studies were eligible for meta-analysis (ie, parallel-design studies comparing BP with TRAD). Average length of these training interventions was 4.9±4.0 weeks (range: 1–12). Four of the studies were conducted on male participants, while the remaining two studies included both males and females. The studies were performed on cyclists in three occasions[11,17,22] and on cross-country skiers,[20] hockey players[21] and alpine skiers[8] in the other three studies. According to De Pauw et al's[33] guidelines to classify subject groups in sport-science research were all

Table 1 Characteristics of the studies and participants

	Groups		Participants			Training intervention			Endurance training					
Authors	**Exp. groups**	**Matched?**	**Sport**	**Sex**	**Training level**	**Exercise form**	**Training**	**Duration (weeks)**	**Avg. freq./ week**	**Exercise intensity**	**Duration/ session**	**Additional/ replacement**	**Supervision**	**Outcomes**
Pyne and Touretski (1993) [case study]	Block periodization		Swimming	Male	Athlete	Swimming	Week 1: LIT focus Week 2: Anaerobic threshold focus Week 3: HIT focus.	3	n/a (61–69 km/week)	LIT, MIT and HIT	n/a	Replacement	n/a	Blood lactate responses
Garcia-Pallarés et al (2009) [one group-design]	1. Block periodization		11 Kayakers	Male	Athletes	Kayaking and resistance exercises	3 blocks (1. VT_2-focus, 5 weeks. 2. VO_2max-focus, 5 weeks. 3. Competition pace-focus, 2 weeks.).	12	12.5	70–100% VO_2max	20–120 mins	Replacement	Yes	VO_2max, maximal paddling speed, VT_2, 1RM, muscle power assessments
Breil et al (2010) [two group-design] Meta: YES	1. HIT block periodization	No	13 Alpine skiers	Mixed	Athletes	Bicycling and obstacle running	3x3 days with HIT blocks (5 HIT sessions per block).	1.6	9.6	90–95% HRmax	16 mins HIT	Replacement (resistance training in addition)	Yes	VO_2max, Wmax, TTE @ 90% pre-Wmax, VT_1, VT_2, SJ, CMJ
	2. Control training		8 Alpine skiers	Mixed	Athletes	n/a	Continued normal training.	1.6	n/a	n/a	n/a		n/a	
Garcia-Pallarés et al (2010) [crossover design]	1. Block periodization	No	10 Kayakers	Male	Athletes	Kayaking and resistance exercises	3 blocks (1. VT_2-focus, 5 weeks. 2. VO_2max-focus, 5 weeks. 3. Competition pace-focus, 2 weeks.).	12	n/a	70–100% VO_2max	20–120 mins	Replacement	Yes	VO_2max, maximal paddling speed and power, VT_2
	2. Traditional periodization		"	"	"	Kayaking and resistance exercises	3 blocks (1. VT_2-focus, 12 weeks. 2. VO_2max-focus, 6 weeks. 3. Competition pace-focus, 4 weeks.).	22	n/a	70–100% VO_2max	20–120 mins	Replacement	Yes	
Mallo (2011) [one group-design]	Block periodization		1 Soccer team	Male	Athletes	Running, resistance exercises, flexibility	4 consecutive seasons where each season was structured into three training stages which were further subdivided into three training blocks.	4 seasons á 309±10 days	n/a	LIT and HIT	n/a	Replacement	n/a	Points obtained in matches, table position

(*Continued*)

Table 1 (Continued).

	Groups		Participants			Training intervention			Endurance training					
Authors	**Exp. groups**	**Matched?**	**Sport**	**Sex**	**Training level**	**Exercise form**	**Training**	**Duration (weeks)**	**Avg. freq./ week**	**Exercise intensity**	**Duration/ session**	**Additional/ replacement**	**Supervision**	**Outcomes**
Mallo (2012) [one group-design]	Block periodization		22 Soccer players	Male	Athletes	Running, resistance exercises, flexibility	One season that was structured into five training stages which were further subdivided into three training blocks.	44	n/a	LIT and HIT	n/a	Replacement	n/a	Yo-Yo-test, CMJ, 10-m sprint
Støren et al (2012) [case study]	Increased HIT volume and reduced total training volume (with HIT blocking)		1 Cyclist	Male	Athlete	Running and bicycling	~4 months preseason training: 3 HIT sessions/ week +2 HIT blocks á 14 sessions in 9 days.	52 (~17 weeks with experimental training)	~4.4	90–95% HRmax	16 mins HIT	Replacement of HIT, reduced total training volume	n/a	VO_2max, lactate threshold, cycling economy, TT performance
Wahl et al (2013) [two group-design]	HIT block periodization with active recovery	Yes, by HIT volume	8 triathletes	Mixed	Athletes	Bicycling, running and swimming	3x3 days with HIT blocks (4–5 HIT sessions per block) +1 extra day with two HIT sessions. Active rest periods between intervals.	2	7.5	90–95% HRmax	~15 mins HIT	Replacement	Yes	VO_2max, Wmax, VT_1, VT_2, TT performance, Wingate, Hb_{mass}
	HIT block periodization with passive recovery		8 triathletes	Mixed	Athletes	Bicycling, running and swimming	3x3 days with HIT blocks (4–5 HIT sessions per block) +1 extra day with two HIT sessions. Passive rest periods between intervals.	2	7.5	90–95% HRmax	~15 mins HIT	Replacement	Yes	
Rønnestad et al (2014) [two group-design] Meta: YES	1. HIT block periodization	Yes, by total and intensity-specific training volume	10 Cyclists	Male	Athletes	Bicycling	5 HIT sessions in week 1, thereafter 1 HIT session/week in week 2–4.	4	2	88–100% HRmax	30 mins HIT	Replacement of HIT training	n/a	VO_2max, Wmax, power @ 2mmol/L [La^-], cycling economy, gross efficiency
	2. Traditional organization		9 Cyclists	Male	Athletes	Bicycling	2 HIT sessions/week.	4	2	88–100% HRmax	30 mins HIT	Replacement of HIT training	n/a	

(*Continued*)

Table 1 (Continued).

	Groups		Participants			Training intervention			Endurance training					
Authors	**Exp. groups**	**Matched?**	**Sport**	**Sex**	**Training level**	**Exercise form**	**Training**	**Duration (weeks)**	**Avg. freq./ week**	**Exercise intensity**	**Duration/ session**	**Additional/ replacement**	**Supervision**	**Outcomes**
Rønnestad et al (2014) [two group-design] Meta: YES	1. HIT block periodization	Yes, by total and intensity-specific training volume	8 Cyclists	Male	Athletes	Bicycling	3 blocks á 4 weeks. Each block with 5 HIT sessions in week 1, thereafter 1 HIT session/week in week 2–4.	12	2	88–100% HRmax	30 mins HIT	Replacement of HIT training	n/a	VO_2max, Wmax, power @ 2mmol/L [La^-], 40min all-out test, gross efficiency, Hb_{mass}
	2. Traditional organization		7 Cyclists	Male	Athletes	Bicycling	2 HIT sessions/week.	12	2	88–100% HRmax	30 mins HIT	Replacement of HIT training	n/a	
Wahl et al (2014) [one group-design]	HIT block periodization		12 Soccer players	Male	Athletes	Running, dribbling tracks and small-sided games	4×2–3 days with HIT blocks (2–4 HIT sessions per block).	1.9	6.5	90-95% HRmax	16 mins HIT	Additional	n/a	Yo-Yo-test, RSA test, CMJ
Clark et al (2014) [three group-design] Meta: YES	Short sprints block	Yes, by total and HIT volume	9 Cyclists	Male	Athletes	Cycling	Short sprints, 5–20 s. 7 consecutive days.	1	7	All-out	15 mins sprinting	Replacement	Yes	VO_2max, Wmax, power @ OBLA, gross efficiency, TT performance
	Long sprints block		10 Cyclists	Male	Athletes	Cycling	Long sprints, 15–45 s. 7 consecutive days.	1	7	All-out	15 mins sprinting	Replacement	Yes	
	Control		9 Cyclists	Male	Athletes	Cycling	Continued normal training. Same amount of total training as exp. groups.						n/a	
Fernandez-Fernandez et al (2015) [one group-design]	HIT block periodization		12 Tennis players	Male	Athletes	Tennis-specific HIT sessions	5×2–3 days with HIT blocks (2–3 HIT sessions per block).	2.4	5.4	90–95% HRmax or V_{IFT}	~15 mins HIT	Additional	Yes	30:15 intermittent fitness test, RSA test, CMJ, 20-m sprint
Rønnestad et al (2016) [two group-design] Meta: YES	HIT block periodization	Yes, by total and intensity-specific training volume	10 XC-skiers	Mixed	Athletes	Uphill cross-country skiing	5, 1, 3, 1, 1 HIT sessions/week in week 1–5.	5	2.2	88–100% HRmax	30 mins HIT	Replacement of HIT training	n/a	VO_2max, Wmax, power @ 4mmol/L [La^-], fractional utilization of VO_2max, work economy
	Traditional organization		9 XC-skiers	Mixed	Athletes	Uphill cross-country skiing	2, 2, 3, 2, 2 HIT sessions/week in week 1–5.	5	2.2	88–100% HRmax	30 mins HIT	Replacement of HIT training	n/a	

(*Continued*)

Table 1 (Continued).

	Groups		Participants			Training intervention			Endurance training					
Authors	**Exp. groups**	**Matched?**	**Sport**	**Sex**	**Training level**	**Exercise form**	**Training**	**Duration (weeks)**	**Avg. freq./ week**	**Exercise intensity**	**Duration/ session**	**Additional/ replacement**	**Supervision**	**Outcomes**
Rønnestad et al (2016) [case study]	HIT block		1 Cyclist	Male	Athlete	Cycling	7 consecutive days with 3 sets of 9.5 mins of 30 swork intervals interspersed with 15 s recovery.	1	7	Highest possible average power output	28.5 mins HIT	Replacement	n/a	VO_2max, Wmax, power @ 2mmol/L [La^-], maximal voluntary torque, SJ
Manchado et al (2017) [crossover design]	Block periodization	Yes, by total endurance training volume	11 Handball players	Female	Athletes	Running, handball-specific endurance exercises and resistance exercises	ACC (5 weeks)-, TRA (5 weeks)-, and REA (6 weeks) period focusing on maximal three physical abilities/period.	16	3/2 endurance sessions (ACC/TRA period, resp.)	85–95% HRmax	25–30 mins	Replacement	n/a	VO_2max, throwing velocity, SJ, CMJ, maximal strength, 20-m sprint
	Traditional organization		"	"	"	"	GP (4 weeks)-, SP (4 weeks)-, and C (8 weeks) period focusing on mixed, multitargeted training.	16	3/2 endurance sessions (GP/SP period, resp.)	70–85% HRmax	25–40 mins	Replacement	n/a	
McGawley et al (2017) [crossover design]	Block periodization	Yes, by total and intensity-specific training volume	20 XC-skiers	Mixed	Athletes	Cross country skiing, running and resistance exercises	9 HIT sessions in week 2 (0 in week 1 and 3), 4 and 5 LIT sessions in week 1 and 3 (0 in week 2), 3 resistance training sessions in week 1 and 3 (0 in week 2).	3	6	60–100% HRmax	20 mins HIT sessions, 58–127 min LIT sessions	Replacement	Yes	VO_2max, work economy, TT performance, muscle characteristic (capillary density, fiber area, fiber type distribution, oxidative and glycolytic enzymes activity)
	Evenly-distributed training		"	"	"		3 HIT sessions/week, 2–3 LIT sessions/week and 2 resistance training sessions/week.	3	5.3	60–100% HRmax	20 mins HIT sessions, 58–127 min LIT sessions	Replacement	Yes	

(*Continued*)

Table 1 (Continued).

	Groups		Participants			Training intervention			Endurance training					
Authors	**Exp. groups**	**Matched?**	**Sport**	**Sex**	**Training level**	**Exercise form**	**Training**	**Duration (weeks)**	**Avg. freq./ week**	**Exercise intensity**	**Duration/ session**	**Additional/ replacement**	**Supervision**	**Outcomes**
Rønnestad et al (2018) [two group-design] Meta: YES	HIT and resistance training block periodization	Yes, by total and intensity-specific training volume	8 Ice hockey players	Male	Athletes	Bicycling and resistance exercises	HIT-focus in week 2 and 5 (5 sessions/week) and focus on resistance training the other weeks (1 HIT session/week).	6	2.3	"Maximal sustainable work intensity"	28.5 mins HIT	Replacement of HIT and resistance training	Yes	VO_2max, Wmax, Wingate, maximal torque, SJ
	Traditional periodization		8 Ice hockey players	Male	Athletes	Bicycling and resistance exercises	2–3 HIT sessions and 5–6 resistance training sessions each week.	6	2.3	"Maximal sustainable work intensity"	28.5 mins HIT	Replacement of HIT and resistance training	Yes	
Rønnestad et al (2018) [case study]	Block periodization		1 Cyclist	Male	Athlete	Bicycling and resistance exercises	Training blocks lasting 1–2 weeks focusing on LIT, MIT and HIT separately, while maintaining the others.	58	n/a (~12hrs/ week)	60–100% HRmax	16–420 mins	Replacement	n/a	VO_2max, Wmax, power @ 3mmol/L [La^-]
Strøm Solli et al (2019) [case study]	Block periodization	Season 2005–2006	1 Cross country skier	Female	Athlete	Skiing, running, cycling, resistance exercises	Block periodization of HIT training: 7 HIT blocks of 7–11 days including 8–13 HIT sessions. 121% higher total HIT volume than TRAD.	52	157 HIT sessions in total	60–100% HRmax	n/a	Replacement	n/a	World Cup victories and ranking
	Traditional periodization	Season 2014–2015	Ibid.	Female	Athletes	Skiing, running, cycling, resistance exercises	Traditional periodization. 15% and 70% higher LIT ant MIT volume than BP.	52	77 HIT sessions in total	60–100% HRmax	n/a	Replacement	n/a	

Abbreviations: ", "the same as above"; HIT, high-intensity training; MIT, moderate-intensity training; LIT, low-intensity training; VO_2max, maximal oxygen uptake; Wmax, peak power output; TTE, time to exhaustion; VT_1, first ventilatory threshold; VT_2, second ventilatory threshold; SJ, squat jump height; CMJ, counter movement jump height; 1RM, one-repetition maximum; HRmax, maximal heart rate; [La^-], capillary lactate concentration; Hb_{mass}, hemoglobin mass; TT, time trial; V_{IFT}, velocity obtained in the intermittent fitness test; RSA, repeated sprint ability; XC-skiers, cross-country skiers; ACC, accumulation; TRA, transformation; REA, realization; GP, general preparation; SP, specific preparation; C, competition; OBLA, onset of blood lactate accumulation.

experimental groups classified as trained or well-trained (performance level ≥3) at baseline for absolute peak power output (all groups >339 W). This was the same for relative VO_2max (performance level ≥3; >55 mL·min^{-1}·kg^{-1}), except for one study[8] where the subjects were classified as recreationally trained (performance level 2; 53 mL·min^{-1}·kg^{-1}).

PEDro scores for included parallel design-studies are shown in Table 2. The 10 included studies achieved a mean PEDro score of 3.7/10. Six of the studies achieved a rating of moderate quality, while the remaining four studies were of low quality.

Calculation of effect sizes for meta-analysis

VO_2max and Wmax were evaluated in the meta-analysis since these two are considered to be the most important predictors of endurance performance[33] and were the most common reported variables across studies. Other variables were not highlighted in the meta-analysis considering the test protocols being to heterogenetic for comparison in a meta-analysis (ie, measures of anaerobic threshold).

Standardized mean difference estimates with their corresponding sampling variance were computed for VO_2max and Wmax for BP and TRAD groups in each study with eq. (1),

$$g = c(m)(n-1)\left(\frac{x_{post} - x_{pre}}{SD_{pre}}\right) \quad (1)$$

where x_{post} and x_{pre} are the means of BP and TRAD's pretest and posttest and SD_{pre} is the standard deviation of the pretest scores. $c(m) = \sqrt{2/m\Gamma[m/2]/\Gamma[(m-1)/2]}$ is a bias-correction factor for adjustment of small samples.[34] The sampling variance for the standardized mean difference was computed with the formula eq. (2),

$$var(g_{ij}) = \frac{2(1-r_{ij})}{n_{ij}} + \frac{(g_{ij})^2}{2n_{ij}} \quad (2)$$

where g_{ij} is the unbiased standardized mean change and r_{ij} is the estimate of the pre-post test correlation for group j of study i. The difference in the two standardized mean change scores was then calculated with eq. (3),

$$g = g_{(T)} - g_{(C)} \quad (3)$$

where $g_{(T)}$ and $g_{(C)}$ are the BP and TRAD group, respectively. The calculation of standardized mean difference and sampling variance were computed based on equations from Becker[34] and Morris[35] using the metafor package for R.[36]

Statistical analysis

Meta-analysis was fitted using a random-effect model threating variation between studies as a random effect and variation between BP and TRAD groups as random effects nested within studies.[35,37] Model parameters (amount of heterogeneity) were estimated by the Paule-Mandel-estimator with a Knapp and Hartung adjustment.[37,38] Studies were weighted by the inverse of the sampling variance. The heterogeneity among studies was explored using T^2 and I^2, with values of 20%, 50% and 75% indicating low, moderate and high heterogeneity, respectively.[39] The meta-analysis was modulated using the metafor package for R.[36] Due to the limited number of studies which in turn reduces the overall power for the models, moderator or sub-groups analysis were not performed.[39] If a study had three comparison groups, the intervention groups were combined as recommended by the Cochrane handbook.[39] The criteria to interpret the magnitude of the effect size (ES) were the following: 0.0–0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large and >2.0 very

Table 2 PEDro scores

Authors	PEDro Scale: item number											Total	Rating
	1	2	3	4	5	6	7	8	9	10	11	score	
Breil et al (2009)	Yes	0	0	0	0	0	0	1	0	1	1	3	Low
Garcia-Pallarés et al (2010)	No	0	0	1	0	0	0	0	0	1	1	3	Low
Rønnestad et al (2014)	No	0	0	1	0	0	0	1	0	1	1	4	Medium
Rønnestad et al (2014)	No	0	0	1	0	0	0	1	0	1	1	4	Medium
Wahl et al (2013)	No	0	0	0	0	0	0	1	0	1	1	3	Low
Clark et al (2014)	Yes	0	0	1	0	0	0	1	0	1	1	4	Medium
Rønnestad et al (2016)	No	1	0	1	0	0	0	1	0	1	1	5	Medium
Manchado et al (2017)	No	0	0	1	0	0	0	0	0	1	1	3	Low
McGawley et al (2017)	No	1	0	0	0	0	0	1	0	1	1	4	Medium
Rønnestad et al (2018)	No	1	0	0	0	0	0	1	0	1	1	4	Medium

large.[40] ESs (Cohen's *d*) for endurance performance, exercise economy/efficiency and workloads at different exercise thresholds are presented as calculated in the original articles.

Results

Meta-analyses

The VO_2max and Wmax analyses comprised 107 subjects, nested within 6 studies. Figures 2 and 3 show a summary of the data and each study`s standardized mean difference as well as the pooled size.

Maximal oxygen uptake

The overall ES for VO_2max of 0.40 (95% CI=0.02, 0.79) shows a small favor for BP compared to TRAD and the null hypothesis was rejected (t=2.7, p=0.04). The prediction interval (95% CI=−0.32, 1.12) implied that the true effect in 95% of study settings is uncertain. The T^2=0.06 and I^2=48.4% implies low-to-moderate variance among the true effect.

Maximal power output

Wmax showed an overall ES of 0.28 (95% CI=0.01, 0.54) which elucidates a small favor of BP compared to TRAD and the null hypothesis is rejected (t=2.6, p=0.04). The prediction interval (95% CI=−0.18, 0.73) states that the true effect in 95% of study settings is uncertain. The T^2=0.02 and I^2=34.0% implies low-to-moderate variance among the true effect.

Systematic review

Endurance performance was assessed in eight of the examined studies

Measures of closed-end cycling performances was conducted in five studies[11,12,17,19,29]. Rønnestad et al[11] observed an increased mean power output during 40 mins cycling in both groups (BP: 8.2±5.7%, TRAD: 4.1±3.1%). This revealed a moderate ES in favor of BP training compared to TRAD (ES=0.89), although the difference in relative changes between the two groups was not significant (p=0.12). Wahl et al[19] did also find a superior mean power output in 20 mins cycling performance after 2 weeks BP. Interestingly, the group that did passive recovery between high-intensity training (HIT) interval bouts tended to increase more than the group performing active recovery (passive recovery, +27±10 W; active recovery, +14±18 W; p=0.09). A shorter block of 7 days with consecutive maximal intensity sprinting sessions did also augment time trial performance (computer-simulated 20 km) were long sprints (15–45 s) gave the same improvement in mean power output as shorter sprints (5–20 secs; +6.8±5.8% and +4.6 ±4.4%, respectively),[17] which was significantly different

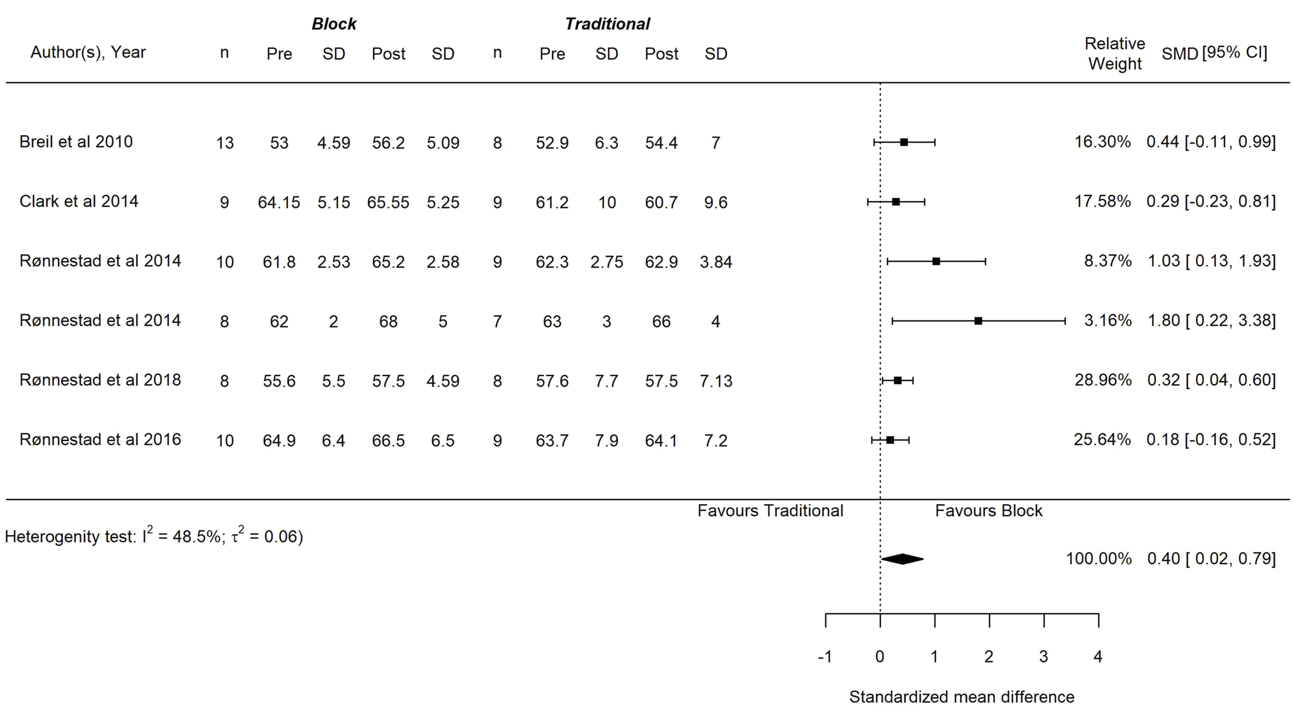

Figure 2 Forest plot of studies comparing the changes in maximal oxygen consumption (mL·min^{-1}·kg^{-1}) between block and traditional periodization training. The data shown as standardized mean difference (SMD) are mean [95% CI]. Weight=statistical weight of each study.

Author(s), Year	Block n	Block Pre	Block SD	Block Post	Block SD	Traditional n	Traditional Pre	Traditional SD	Traditional Post	Traditional SD	Relative Weight	SMD [95% CI]
Breil et al 2010	13	347	67	363	73	8	339	63	346	59	17.86%	0.12 [-0.26, 0.51]
Clark et al 2014	9	339	24	357.5	23.5	9	345	36	339	37	12.01%	0.85 [0.33, 1.36]
Rønnestad et al 2014	10	408.7	27.67	417.5	32.9	9	413.8	36.1	415.2	40.4	18.73%	0.26 [-0.12, 0.63]
Rønnestad et al 2014	8	409.4	29.7	434.4	35.8	7	425	32.3	439.3	32.6	6.06%	0.36 [-0.41, 1.14]
Rønnestad et al 2018	8	358	36.3	373	37	7	355	28.4	365	35	21.67%	0.06 [-0.27, 0.39]
Rønnestad et al 2016	10	344.8	79.9	356.6	78.6	9	360.9	50.9	351.9	55.9	23.67%	0.29 [-0.01, 0.60]
Heterogenity test: $I^2 = 34.0\%$; $\tau^2 = 0.02$)											100.00%	0.28 [0.01, 0.54]

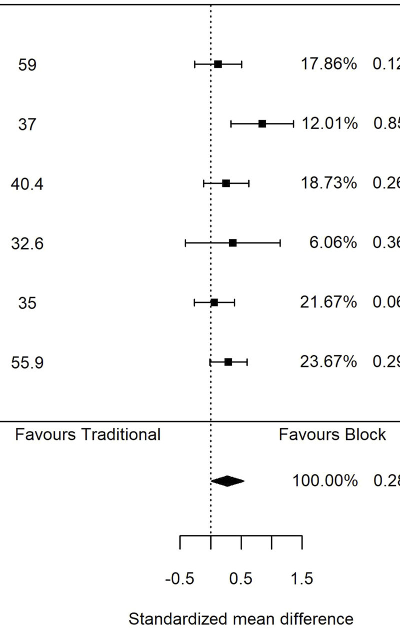

Figure 3 Forest plot of studies comparing the changes in maximal power output (Wmax) between block and traditional periodization training. The data shown as standardized mean difference (SMD) are mean [95% CI]. Weight=statistical weight of each study.

from the TRAD group (−3.3±4.2%; *p*<0.01, ES=0.67–0.82). In the case study of Støren et al,[29] a 15% improvement was evident on their ~23-km indoor-bike time trial. In contrast to this, time trial performance (600-m treadmill rollerski time trial at 6° gradient) was only improved after TRAD of HIT (−3±5 s; *p*<0.05, ES=0.44) and not after BP of HIT (−1±6 s) in cross-country skiers.[12] The changes were however not statistically different between groups.

One study[8] conducted a time-to-exhaustion test at a workload corresponding to 90% of the athletes' pre-intervention Wmax for evaluation of endurance performance. However, neither BP nor TRAD enhanced the performance (*p*>0.05). On the other hand, 13 days of BP in soccer players revealed a large improvement in Yo-Yo Intermittent Recovery Test Level 2 (from 407±43 m to 507±57 m, *p*<0.05; ES=1.92).[26] The same was evident in Mallo et al's[25] seasonal monitoring (Yo-Yo Intermittent Recovery Test Level 1, from 2037±264 m to 2676±255 m; *p*<0.01) and after a comparable BP intervention were the players improved their maximal speed during the 30–15 Intermittent Fitness Test by 6.5±2.9% (*p*<0.001).[27]

Workloads at different exercise thresholds

Cyclists have revealed tendencies to greater improvements of power output at 2 mmol·L^{-1} lactate concentration following both 4[22] and 12 weeks[11] with BP. The 4-week intervention gave a 10±12% increase in BP, while no changes were observed in TRAD, with no statistically significant differences between the groups, but the ES was in favor of BP (ES=0.71). For the 12-week study, the relative improvements were 22 ±14% and 10±7% for BP and TRAD, respectively. This revealed an even larger ES of BP compared to TRAD (*p*=0.054; ES=1.12). In another study, a 1-week training block enhanced power output at onset of blood lactate accumulation with ~7% (ES=0.53–0.60) compared to volume-matched TRAD, regardless if the block training was performed as long or short sprints (*p*<0.05).[17] In a study comparing BP with either passive or active recovery between HIT interval bouts only the group that did passive recovery improved power output at second ventilatory threshold.[19] A greater difference in change was also present compared to active recovery (*p*<0.05; ES=0.52). In long-term case-studies, 58 and 17 weeks of BP revealed a 36% improvement in power output at 3 mmol·L^{-1} lactate concentration and 14% increase in power output at lactate threshold, respectively.[29,31] BP and TRAD were equally effective in improving paddling power at second ventilatory threshold (+10% vs +11%, respectively) in rowers,[9] while in cross-country, skiers were BP superior to TRAD in improving power output at 4 mmol·L^{-1} lactate concentration (11±10% and 2±4%, respectively; *p*<0.01; ES=1.26) after a 5-week training period.[20]

Exercise efficiency and economy

Rønnestad et al[11] observed a non-significant improvement in gross efficiency for their BP training group (from 20.3% to 20.9%; p=0.12). The relative improvement corresponded to a moderate ES in advantage of BP compared to TRAD training (ES=1.10; TRAD, from 19.6% to 19.5%). Quite similar results were present in Clark et al[17] where none of the groups changed gross efficiency significantly (p>0.05; 5.1±3.9%, 3.2±2.4% and 1.5±4.3% improvement for BP with long sprints, BP with short sprints and TRAD training, respectively). However, the relative improvement of gross efficiency for short and long sprints revealed small to moderate ESs compared to TRAD (ES=0.26 and 0.65, respectively).[17] Similarly, neither BP nor TRAD changed skiing economy following 5 weeks of HIT-training,[20] whereas McGawley et al,[12] on the other hand, showed improvement in skiing economy in TRAD only.

Discussion

The present study investigated the effects of BP on factors determinative for endurance performance and endurance performance measurements based on systematic analyses of pooled data from the existing literature. The meta-analyses revealed evidence for beneficial effects of BP compared to TRAD regarding VO_2max and Wmax in trained athletes. Due to a lack of studies and heterogeneity between the tests used to evaluate endurance performance measures, workloads at different exercise thresholds and exercise efficiency/economy, meta-analyses were not performed for these factors. However, the vast majority of these data revealed either beneficial or similar effects for BP compared to TRAD. The findings emphasize that BP, as defined in the present paper, is an adequate, alternative strategy with potentially greater training effects than TRAD for trained to well-trained athletes. Nonetheless, the number of eligible studies are quite small (n=10) and they achieved only low-to-moderate PEDro scores. Some methodological considerations when interpreting the efficacy of BP are therefore important to address.

Meta-analysis of VO_2max and Wmax

The included studies in the meta-analyses comprised young (25±7 years), trained athletes with average VO_2max of 60±4 $mL \cdot min^{-1} \cdot kg^{-1}$ and Wmax of 367±33 W. The selection of participants requires that several aspects need to be elucidated regarding the external validity of these results. From an applied point of view, these results indicate that trained individuals, within a relatively short duration of time (4.9 weeks average study length; range, 1–12 weeks) can benefit from BP by a more efficient improvement of VO_2max and Wmax compared to TRAD. The pooled ES of BP on VO_2max was 0.40 (t=2.7, p=0.04) and Wmax was 0.28 (t=2.6, p=0.04). Although this per se is considered small effects,[40] this may actually be an important effect considering that the athletes included in these analyses have performed a substantial training volume over a number of years before inclusion. For this reason, substantial improvements are not commonly observed in this population.[41] With this in mind, BP seems to be a beneficial training strategy that successfully can enhance an athlete`s VO_2max and Wmax further, at least in the short term. BP gave approximately the same ES for VO_2max and Wmax, which is quite reasonable since they are previously shown to be closely related.[42]

The included studies were conducted in the preseason and lasted ≤12 weeks. Therefore, the effect of BP during the competitive season or in the longer term is not adequately explored. Nonetheless, some evidence is available for a beneficial effect of BP training also in a long-term perspective. Two single-case studies of elite cyclists revealed an increased VO_2max and Wmax of 10–20% following 58 and 17 weeks of BP performed in training cycles of ~1–2 weeks.[29,31] However, a female elite cross-country skier, who trained two seasons with either a BP or TRAD focus, showed no difference in the number of World Cup victories or ranking, indicating successful utilization of both training models.[32] The latter is not surprising since years of TRAD is a well-established and efficient training strategy to enhance performance, as previously shown in case studies.[43,44] Two studies have also compared the effects of BP and TRAD in two consecutive seasons with a cross-over design. Both of these showed a favor of BP in terms of similar or greater increases in VO_2max with either a volume-matched approach[28] or with performing fewer sessions and a shorter training intervention[9] compared to TRAD in elite kayakers and handball players, respectively. These findings indicate that BP can be an alternative to TRAD for elite athletes also in a longer training perspective, even though general methodological weaknesses regarding single-case studies must be considered.

Endurance performance

Clark et al[17] is the only study that observed a statistical improvement after BP compared to TRAD. The positive effects observed in the other studies have either been stated as non-significant superior improvements for BP[11] or have lacked an appropriate control group to evaluate interaction effects.[19] Accordingly, no interaction effects between BP and TRAD were either evidenced for a 600-m cross-country skiing time trial[12] or a time to exhaustion test in cycling.[8] Conversely, large improvements have been observed in endurance performance following 13 and 17 days of BP in soccer and tennis players measured as increased distance covered in Yo-Yo-test and speed at 30–15 test.[26,27] There have also been shown improved time during a 23 km time trial in an elite cyclist following a year using BP.[29] In addition, Mallo[25] displayed an increased Yo-Yo-test performance after a 44-week season following a BP program in professional soccer players. However, all these latter results must be considered with caution due to the lack of control groups[25–27] and the use of case-study design.[29] These somewhat inconsistent findings in endurance performance make it a bit more difficult to interpret the implications of BP. However, the ESs in the studies have generally shown moderate to large effects of BP vs TRAD on endurance performance[11,17,19,25,26] although one has shown a small positive effect of TRAD.[12] Overall, independent of sport discipline or performance assessment, it is pretty consistent that BP seems to improve rather than impair endurance performance.

Workloads at different exercise thresholds, exercise efficiency and economy

BP and TRAD increased power output at a definite exercise threshold in all included studies, except for the TRAD group in Rønnestad et al.[22] Improvements were larger for BP compared to TRAD in cyclists[17] and cross-country skiers[20] at onset of blood lactate accumulation. In contrast, equal improvements of power output at a definite exercise threshold have been observed in kayakers,[9] whereas one study observed a tendency in favor of BP[11] and another study observed a within-change for BP, but not for TRAD and no significant change between groups.[22] Again, implication of BP is divergent. Interestingly, Garcia-Pallarés et al[9] trained approximately half of the volume in BP compared to TRAD (12 vs 22 weeks) and increased power output at second ventilatory threshold to the same extent. This can support the feasibility of concentrated stimuli for enhancing exercise threshold, in addition to the general moderate to large ESs in favor of BP.[11,17,20,22] Moreover, considering the case-studies with their limitations, long-term effect of BP shows substantial improvements of 14% and 36% in exercise threshold power output.[29,31] When it comes to exercise efficiency and economy, there are too few studies to make a discussion of them. Furthermore, taken the relatively short intervention period in the included studies and the high training status of the athletes, non or only minor changes in this variable would be expected.[45–47]

To BP, or not to BP

The somewhat divergent results reviewed in this paper and the uncertainty with statistical models complicate the interpretation of the efficacy of BP. We suggest that BP should be considered in a holistic perspective, meaning that training history, training goals and everyday life situation among other factors should be evaluated before BP is integrated as a part of an athlete training program. There is consensus among researchers that variation and progression in training stimulus is necessary to augment physiological adaptations and to continuously develop endurance performance.[44] In this context might both Issurin's and the alternative model of BP display an advantage; TRAD induces smaller variations between mesocycles/microcycles than BP. However, within a microcycle/mesocycle TRAD will induce larger variations than BP. In response to this, the highly concentration of specific training in BP seems to be an advantage for inducing adaptations in well-trained athletes. Nevertheless, whether the enhancement of VO_2max, Wmax or endurance performance is related to changes in training stimulus or BP per se is still difficult to elucidate. Rønnestad et al[20] tried to accommodate this question by implementing variations of HIT stimuli (two and three sessions per week) within a mesocycle of TRAD. In this volume-matched HIT and low-intensity training design, BP was superior in developing Wmax and power output corresponding to 4 mmol·L^{-1} blood lactate concentration.

Regardless of whether the superior training effects of BP are related to BP itself or just a variation in stimuli, they both are closely intertwined. Training variation in the long-term planning is systematically applied in both the BP and TRAD model.[6] So, in the long-term training plan both models aim to dynamically balance training with the purpose of avoiding dilution of training effects and the negative effects of monotony.[5,6] Therefore, in the lack of an universally accepted definition of periodization,[6] it might in some cases be difficult to distinguish between the two distinct models since they both are using some sort of variation in the organization of (long-term) training. The included studies are generally characterized by introduction of specific block(s) subsequent to a period with TRAD. This might just be a way of manipulating training to achieve a variation in training stimuli to optimize endurance improvements within the annual periodization plan. However, the long-term effects of this organization may not directly be answered by the relatively short-term studies conducted so far in the literature. The direction of future research should be emphasized to investigate the long-term effects of several blocks throughout a whole season, compared to the TRAD model, on performance, physiological and biological performance determinants.

The cross-over- and case-studies included have generally implemented multitargeted BP programs.[9,23–25,28,31] They are characterized by a prolonged nature, conducted over one training season or consecutive seasons. We should not underrate these study designs since these studies demonstrate greater ecological validity due to a more real-world setting. These studies have mainly employed the Issurin model of BP with three specific mesocycles; accumulation, transmutation and realization, whereby a minimum of different physiological abilities, eg, Wmax and maximal muscle strength,[9] have been focused in a particular mesocycle. This is to a certain extent different to the alternative BP model were a specific ability is focused (ie, VO_2max) in each microcycle, while other abilities are maintained (ie, muscular strength) with typically one session.[11,21] Independent of the two BP models the existing evidence displays that both models are successful promotors of training adaptations and efficient training strategies both for team and individual sports, although the effect in team sports is less explored.

Overall, the reviewed studies displayed low to medium quality according to the PEDro scale. More or less all studies are at a higher risk of bias, mostly because of lack of blinding of testers and specifying randomization (Table 2). Furthermore, all except two studies[8,17] did not provide eligibility criteria for the study participants. It may therefore be a question whether selection bias has occurred. In addition, the definite direction of the effects and the magnitude of such training have to be interpreted with some caution when considering the 95% prediction interval in the meta-analyses. The prediction interval, which addresses the actual dispersion of the true ES[48] is again wider for VO_2max (95% CI=−0.32, 1.12) as compared to Wmax (95% CI=−0.18, 0.73). Both prediction intervals overlap coverage of the confidence intervals for the point estimates, which suggests that the true effect might fall beyond the confidence intervals for each respective point estimate and therefore reveals an uncertainty for the true effect of BP.

Regarding the small number of available data used in the meta-analyses, the estimated between-study variance can be particularly inaccurate. We controlled for this factor by using the Knapp and Hartung adjustment[36] together with the Paule–Mandel heterogeneity estimator, which are suggested to be more robust and produce less bias when sample size and study number is low.[37,38] Heterogeneity scores for both models showed low-to-moderate heterogeneity considering the I^2 and T^2 scores (Figures 2 and 3), which implies that the models are valid.[37] It is also important to examine the potential for publication bias. According to Sterne et al,[49] interpretation of a funnel plot asymmetry should not be emphasized when there are <10 studies in a meta-analysis due to a lack of test power making it difficult to distinguish chance (ie, false positive findings) from real asymmetry. To accommodate the concern of asymmetry both a fixed- and random-effect model was fitted for both VO_2max and Wmax, indicating the same magnitude of the effects between the models.

Conclusion

Irrespective of the BP models used, the meta-analyses showed favorable effects of BP for VO_2max and Wmax, and the consistency in moderate-to-large ESs displayed for both workload at different exercise thresholds and endurance performance measurements in BP suggests also superior adaptations compared to TRAD. In general, these results seem promising, but since majority of the reviewed studies are small and of low methodological quality, the results must be considered with this in mind.

Disclosure

The authors report no conflicts of interest in this work.

References

1. Issurin VB. New horizons for the methodology and physiology of training periodization. *Sport Med*. 2010;40(3):189–206. doi:10.2165/11319770-000000000-00000
2. Goutianos G. Block periodization training of endurance athletes: a theoretical approach based on molecular biology. *Cell Mol Exerc Physiol*. 2016;4:2. doi:10.7457/cmep.v4i2.e9
3. Issurin VB. Biological background of block periodized endurance training: a review. *Sport Med*. 2019;49(1):31–39. doi:10.1007/s40279-018-1019-9
4. Kiely J, Pickering C, Halperin I. Comment on "biological background of block periodized endurance training: a review. *Sports Med*. 2019;49(1):31–39. doi:10.1007/s40279-019-01114-9
5. Koprivica V. Block periodization - a breakthrough or a misconception. *SportLogia*. 2012;8(2):163–175. doi:10.5550/sgia.120802.en.093K
6. Kiely J. Periodization paradigms in the 21st century: evidence-led or tradition-driven? *Int J Sports Physiol Perform*. 2012;(7):242–250. doi:10.1123/ijspp.7.3.242
7. Pyne DB, Touretski G. An analysis of the training of Olympic sprint champion Alexandre Popov. *Aust Swim Coach*. 1993;10(5):5–14.
8. Breil FA, Weber SN, Koller S, Hoppeler H, Vogt M. Block training periodization in alpine skiing: effects of 11-day HIT on VO 2max and performance. *Eur J Appl Physiol*. 2010;109(6):1077–1086. doi:10.1007/s00421-010-1455-1
9. García-Pallarés J, García-Fernández M, Sánchez-Medina L, Izquierdo M. Performance changes in world-class kayakers following two different training periodization models. *Eur J Appl Physiol*. 2010;110(1):99–107. doi:10.1007/s00421-010-1484-9
10. Issurin VB. Benefits and limitations of block periodized training approaches to athletes' preparation: a review. *Sport Med*. 2015;329–338. doi:10.1007/s40279-015-0425-5
11. Rønnestad BR, Ellefsen S, Nygaard H, et al. Effects of 12 weeks of block periodization on performance and performance indices in well-trained cyclists. *Scand J Med Sci Sport*. 2014;24(2):327–335. doi:10.1111/sms.12016
12. McGawley K, Juudas E, Kazior Z, et al. No additional benefits of block- over evenly-distributed high-intensity interval training within a polarized microcycle. *Front Physiol*. 2017;8(June):413. doi:10.3389/fphys.2017.00413
13. Verkhoshansky Y, Verkhoshansky N. *Special Strength Training Manual for Coaches*. Verkhoshansky SSTM; 2011.
14. Moher D, Liberati A, Tetzlaff J, Altman DG, Group TP. Preferred reporting items for systematic reviews and meta-analyses : the PRISMA statement. *PLoS Med*. 2009;6:7. doi:10.1371/journal.pmed.1000097
15. PEDro scale. Physiotherapy evidence database. 1999. Available from: https://www.pedro.org.au/english/downloads/pedro-scale/. Accessed September 4, 2019.
16. Schindelin J, Arganda-Carreras I, Frise E, et al. Fiji: an open-source platform for biological-image analysis. *Nat Methods*. 2012;28(9(7)):676–682. doi:10.1038/nmeth.2019
17. Clark B, Costa VP, Brien BJO, Guglielmo LG, Carl D. Effects of a seven day overload-period of high-intensity training on performance and physiology of competitive cyclists. *PLoS One*. 2014;9(12):1–14. doi:10.1371/journal.pone.0115308
18. Rønnestad BR, Askestad A, Hansen J. HIT maintains performance during the transition period and improves next season performance in well-trained cyclists. *Eur J Appl Physiol*. 2014;114(9):1831–1839. doi:10.1007/s00421-014-2919-5
19. Wahl P, Zinner C, Grosskopf C, Rossmann R, Bloch W, Mester J. Passive recovery is superior to active recovery during a high-intensity shock microcycle. *J Strength Cond Res*. 2013;27(5):1384–1393. doi:10.1519/JSC.0b013e3182653cfa
20. Rønnestad BR, Hansen J, Thyli V, Bakken TA, Sandbakk O. 5-week block periodization increases aerobic power in elite cross-country skiers. *Scand J Med Sci Sport*. 2016;26(2):140–146. doi:10.1111/sms.12418
21. Rønnestad BR, Øfsteng SJ, Ellefsen S. Block periodization of strength and endurance training is superior to traditional periodization in ice hockey players. *Scand J Med Sci Sports*. 2019;29(2):180–188. doi:10.1111/sms.13326
22. Rønnestad BR, Hansen J, Ellefsen S. Block periodization of high-intensity aerobic intervals provides superior training effects in trained cyclists. *Scand J Med Sci Sport*. 2014;24(1):34–42. doi:10.1111/j.1600-0838.2012.01485.x
23. García-Pallarés J, Sánchez-Medina L, Carrasco L, Díaz A, Izquierdo M. Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle. *Eur J Appl Physiol*. 2009;106(4):629–638. doi:10.1007/s00421-009-1061-2
24. Mallo J. Effect of block periodization on performance in competition in a soccer team during four consecutive seasons: a case study. *Int J Perform Anal Sport*. 2011;11(3):476–485. doi:10.1080/24748668.2011.11868566
25. Mallo J. Effect of block periodization on physical fitness during a competitive soccer season. *Int J Perform Anal Sport*. 2012;12(1):64–74. doi:10.1080/24748668.2012.11868583
26. Wahl P, Güldner M, Mester J. Effects and sustainability of a 13-day high-intensity shock microcycle in soccer. *J Sport Sci Med*. 2014;13(2):259–265.
27. Fernandez-Fernandez J, Sanz-Rivas D, Sarabia JM, Moya M. Preseason training: the effects of a 17-day high-intensity shock microcycle in elite tennis players. *J Sports Sci Med*. 2015;14(4):783–791. http://www.ncbi.nlm.nih.gov/pubmed/26664275.
28. Manchado C, Cortell-Tormo JM, Tortosa-Martínez J. Effects of two different training periodization models on physical and physiological aspects of elite female team handball players. *J Strength Cond Res*. 2018;32(1):280–287. doi:10.1519/JSC.0000000000002259
29. Støren Ø, Bratland-Sanda S, Haave M, Helgerud J. Improved VO2max and time trial performance with more high aerobic intensity interval training and reduced training volume: a case study on an elite national cyclist. *J Strength Cond Res*. 2012;26(10):2705–2711. doi:10.1519/JSC.0b013e318241deec
30. Rønnestad BR, Hansen J, Vegge G, Mujika I. Short-term performance peaking in an elite cross- country mountain biker. *J Sport Sci*. 2017;35(14):1392–1395. doi:10.1080/02640414.2016.1215503
31. Rønnestad BR, Hansen J. A scientific approach to improve physiological capacity of an elite cyclist. *Int J Sports Physiol Perform*. 2018;13(3):390–393. doi:10.1123/ijspp.2017-0228
32. Solli GS, Tønnessen E, Sandbakk Ø, Willis SJ. Block vs. traditional periodization of HIT: two different paths to success for the world 's best cross-country skier. *Front Physiol*. 2019;10(April):1–11. doi:10.3389/fphys.2019.00375
33. De Pauw K, Roelands B, Cheung SS, de Geus B, Rietjens G, Meeusen R. Guidelines to classify subject groups in sport-science research. *Int J Sports Physiol Perform*. 2013;8(2):111–122. http://www.ncbi.nlm.nih.gov/pubmed/23428482.
34. Becker BJ. Synthesizing standardized mean-change measures. *Br J Math Stat Psychol*. 1988;41(2):257–278. doi:10.1111/j.2044-8317.1988.tb00901.x
35. Morris SB. Estimating effect sizes from pretest-posttest-control group designs. *Organ Res Methods*. 2008;11(2):364–386. doi:10.1177/1094428106291059
36. Viechtbauer W. Conducting meta-analyses in R with the metafor package. *J Stat Softw*. 2010;36(3):1–48. doi:10.18637/jss.v036.i03
37. Veroniki AA, Jackson D, Viechtbauer W, et al. Methods to estimate the between-study variance and its uncertainty in meta-analysis. *Res Synth Methods*. 2016;7:55–79. doi:10.1002/jrsm.1164

38. Panityakul T, Bumrungsup C, Knapp G. On estimating residual heterogeneity in random-effects meta-regression: a comparative study. *J Stat Theory Appl*. 2013;12(3):253–265.
39. Higgins JP, Green S, editors. Cochrane handbook for systematic reviews of interventions version 5.1.0. *Cochrane Collab*. 2011 [updated March, 2011]. Available from: http://handbook-5-1.cochrane.org/.
40. Hopkins WG, Marshall S, Batterham A, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sport Exerc*. 2009;41(1):3–13. doi:10.1249/MSS.0b013e31818cb278
41. Lucia A, Hoyos J, Chicharro JL. Physiology of professional road cycling. *Sports Med*. 2001;31(5):325–337. doi:10.2165/00007256-200131050-00004
42. Arts FJ, Kuipers H. The relation between power output, oxygen uptake and heart rate in male athletes. *Int J Sports Med*. 1994;15(5):228–231. doi:10.1055/s-2007-1021051
43. Jones AM. The Physiology of the World Record Holder for the Women's Marathon. *Int J Sports Sci Coach*. 2006;1(2):101–116. doi:10.1260/174795406777641258
44. Tønnessen E, Sylta Ø, Haugen TA, Hem E, Svendsen IS, Seiler S. The road to gold: training and peaking characteristics in the year prior to a gold medal endurance performance. *PLoS One*. 2014;9(7):15–17. doi:10.1371/journal.pone.0101796
45. Impellizzeri FM, Marcora SM. The physiology of mountain biking. *Sports Med*. 2007;37(1):59–71. doi:10.2165/00007256-200737010-00005
46. Hopker J, Coleman D, Passfield L. Changes in cycling efficiency during a competitive season. *Med Sci Sports Exerc*. 2009;41(4):912–919. doi:10.1249/MSS.0b013e31818f2ab2
47. Rønnestad BR, Hansen EA, Raastad T. Effect of heavy strength training on thigh muscle cross-sectional area, performance determinants, and performance in well-trained cyclists. *Eur J Appl Physiol*. 2010;108(5):965–975. doi:10.1007/s00421-009-1307-z
48. Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. *Introduction to Meta-Analysis*. Chichester (UK): John Wiley & Sons, Ltd; 2009. doi:10.1002/9780470743386
49. Sterne JA, Sutton AJ, Ioannidis JP, et al. Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials. *BMJ*. 2011;343:0–8. doi:10.1136/bmj.d4002