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ORIGINAL ARTICLE

Performance changes in world-class kayakers following two different training periodization models

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Abstract This study was undertaken to compare training-induced changes in selected physiological, body composition and performance variables following two training periodization models: traditional (TP) versus block periodization (BP). Ten world-class kayakers were assessed four times during a training cycle over two consecutive seasons. On each occasion, subjects completed an incremental test to exhaustion on the kayak ergometer to determine peak oxygen uptake (VO_{2peak}), VO_2 at second ventilatory threshold (VO_2VT2), peak blood lactate, paddling speed at VO_{2peak} (PS_{peak}) and $VT2$ (PS_{VT2}), power output at VO_{2peak} (Pw_{peak}) and $VT2$ (Pw_{VT2}), stroke rate at VO_{2peak} (SR_{peak}) and $VT2$ (SR_{VT2}) as well as heart rate at VO_{2peak} and $VT2$. Volume and exercise intensity were quantified for each endurance training session. Both TP and BP cycles resulted in similar gains in VO_{2peak} (11 and 8.1%) and VO_2VT2 (9.8 and 9.4%), even though the TP cycle was 10 weeks and 120 training hours longer than the BP cycle. Following BP paddlers experienced larger gains in PS_{peak}, Pw_{peak} and SR_{peak} than those observed with TP. These findings suggest that BP may be more effective than TP for improving the performance of highly trained top-level kayakers. Although both models allowed significant improvements of selected physiological and kayaking performance variables, the BP program achieved similar results with half the endurance training volume used in the TP model. A BP design could be a more useful strategy than TP to maintain the residual training effects as well as to achieve greater improvements in certain variables related to kayaking performance.

Keywords Aerobic fitness · Cardiorespiratory · Canoeing · Endurance performance · Power output · Anthropometric

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Introduction

The concept of periodization refers to the manipulation and sequencing of selected training variables (e.g., load, volume, intensity, exercise type) within the framework of specific cycles throughout the year to optimize athletic performance for major competitions. Training periodization models emerged from empirical observations of successful coaches in the field as well as by theoretical constructs developed by training methodologists. The roots of traditional periodization (TP) program design date back to the 1950s and are based on the experiences made in the early days of the Soviet training system (Bompa and Haff 2009; Issurin 2008). TP became the dominant model for over 30 years in almost all sports and performance levels, and still remains in force. The guidelines of the TP model are based on the simultaneous development of many fitness components (e.g. aerobic capacity, maximal aerobic power, maximum strength) within a regular workload distribution. The traditional model is also characterized by using relatively long periods

of time for the development of training goals and the predominance of general over specific training.

In the 1980s, prominent coaches outlined a number of drawbacks of TP that could prevent elite athletes to achieve further performance improvements: (1) conflicting or negative interactions due to the simultaneous development of too many different motor abilities; (2) failure to provide sufficient workload specificity to enable the correct development of selected fitness components; (3) inability to provide multi-peak performances (4–6 peaks within a season) due to the excessive duration of the different training phases; and (4) difficulty for maintaining the residual training effects of previously developed abilities up to the peaking phase (Issurin 2008). The ever-increasing number of competitions and rigorous demands of modern sport at the elite level, together with the aforementioned limitations of the TP model, led to the emergence of a new planning approach called block periodization (BP). The main feature of this model is the use of highly concentrated training loads focused on the consecutive development of a minimal number of motor and technical abilities (Bondarchuk 1988; Issurin 2008). Specialized training cycles called blocks, with a typical duration of 2–6 weeks, are the main functional components of BP. The sequencing of these blocks is intended to build upon the residual training effects of previously developed abilities.

However, despite its widespread use in coaching practice and the extensive lay literature that is available on these periodization models, to the best of our knowledge, there are no published scientific studies that have explored their effectiveness when applied to highly trained subjects. Therefore, the aim of this study was to compare the effects of these two different models (i.e. TP vs. BP) on selected physiological and performance variables in world-class kayakers. It was hypothesized that a BP approach could be more effective than TP for improving elite kayaking performance.

Methods

Subjects

Ten male, elite flatwater kayak paddlers (all finalists at World Championships, including 2 Olympic gold medallists) volunteered to take part in this study. Mean (SD) characteristics of participants were as follows: age 25.6 (2.5) years; height 184.0 (5.9) cm; body mass 85.3 (5.6) kg; training experience 11.2 (2.7) years; annual paddling volume 4,415 (374) km. Paddlers had at least 3 years of familiarization with the testing procedures used in this investigation and all were part of the same squad (i.e. Spanish Canoeing National Team). The study, which complied with the Declaration of Helsinki, was approved by the Bioethics Commission of the University of Seville, and written informed consent was obtained from athletes prior to participation.

Experimental design and approach to the problem

A crossover design was used. During the intervention period, all athletes performed the same training program over two consecutive seasons [Season 1 (S1): 2006/2007; Season 2 (S2): 2007/2008]. In S1, paddlers underwent a training program based on the TP model, whereas a BP model was used in S2. The main goal of S1 was the Flatwater Racing World Championships (August 2007), a qualifying event for the Olympic Games. The main goals for S2 were the European Championships in May 2008 (last Olympics qualifier) and the Beijing Olympic Games in August 2008. This investigation was part of a larger project examining selected physiological and performance variables in world-class kayakers following different training phases (García-Pallarés et al. 2009a).

Figure 1 shows a summary of the training periodization structure used in the present study. Only the first training cycle of each season was analyzed. Both TP (22-week) and BP (12-week) cycles were divided into three phases (A_{TP}, B_{TP}, C_{TP} and A_{BP}, B_{BP}, C_{BP}, respectively). The main endurance training targets for each phase are also shown in Fig. 1. Both 'A' phases (12 weeks for TP; 5 weeks for BP) focused on developing basic fitness components, such as second ventilatory threshold (VT2), muscle hypertrophy and general technical abilities. 'B' phases (6 weeks for TP; 5 weeks for BP) involved increasing event-specific fitness, such us maximal aerobic power (VO_{2max}) and maximal muscle strength. Finally, 'C' phases (4 weeks for TP; 2 weeks for BP) were tapering phases of gradually reduced training volume destined to facilitate the recovery processes, improve specific race-pace strategy and maximize performance for competition.

The main differences between both cycles (TP and BP) were the total training volume performed, as well as the percentage of that volume devoted to develop main endurance training targets (VT2 and VO_{2max}). The relative and absolute training time performed in each cycle and phase within each intensity training zone are shown in Fig. 2 and Table 1, respectively. For endurance training sessions, three training zones were identified according to the exercise intensity: zone 1 (Z1), light intensity, below VT2; zone 2 (Z2), moderate intensity, between VT2 and 90% of VO_{2peak}; and zone 3 (Z3), high intensity, between 90 and 100% of VO_{2peak}. When expressed in relative terms, training time in Z2 and Z3 zones during A_{BP} and B_{BP} was around 10% higher than during A_{TP} and B_{TP}. During C_{BP}, paddlers completed half the total training volume than

Fig. 1 Study design. Summary of training plan, main training targets and testing calendar for both cycles

Cycle	Traditional Periodization (TP)																							
Phase	A_{TP}												B_{TP}						C_{TP}					
Main Target	VT2												VO_{2max}						Tapering					
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Test	T_{TP1}												T_{TP2}						T_{TP3}					T_{TP4}

Cycle	Block Periodization (BP)												
Phase	A_{BP}					B_{BP}					C_{BP}		
Main Target	VT2					VO_{2max}					Tapering		
Week	1	2	3	4	5	6	7	8	9	10	11	12	13
Test	T_{BP1}					T_{BP2}					T_{BP3}		T_{BP4}

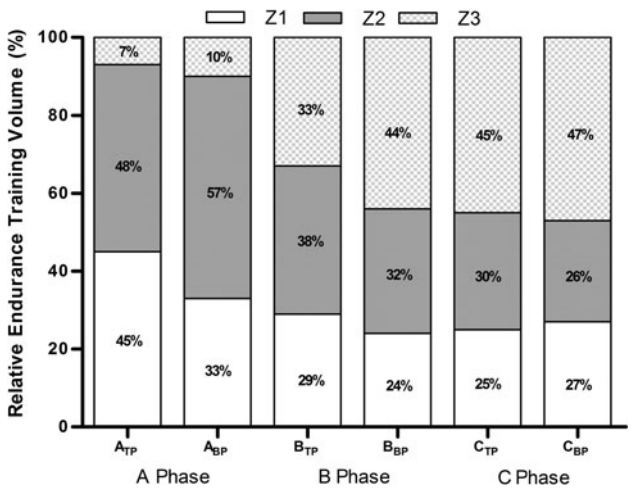

Fig. 2 Relative contribution of each exercise intensity zone to the total endurance training volume performed in each phase and cycle. Zone 1: light intensity, below *V*T2, zone 2: moderate intensity, between *V*T2 and 90% of VO_{2peak}, zone 3: high intensity, between 90 and 100% of VO_{2peak}

during the C_{TP} phase, but the relative contribution over the different training zones was very similar in both tapering phases.

The terminology commonly used in training periodization is often inaccurate, obscure and unnecessarily complex making it difficult for coaches and sport scientists to effectively communicate their findings and the effects produced by different types of training programs. With the aim of simplifying the terminology, the term 'cycle' used in the present study is proposed to delimit periods of time (8–26 weeks) during which all technical and motor abilities needed to ensure success in competition are developed. It matches up well with the 'macrocycle' term usually used in TP and BP. The term 'phase' is used to delimit shorter temporal intervals (2–6 weeks) during which a number of selected training targets are developed. Thus, 'phase' would match up with the terms of 'mesocycle' or 'period' of the TP model, and with the terms 'mesocycle' or 'block' of the BP model.

Training intervention

Before entering both training cycles, participants completed a similar 5-week transition period during which no specific paddling or resistance training were undertaken. Only some recreational physical activities (sport games plus cycling or swimming at low intensities) were performed.

A description of the endurance exercise modes used for training in each intensity zone is shown in Table 2. Training volume and intensity were carefully controlled and quantified by experienced canoeing coaches during each training session throughout both cycles. The main variables used for endurance training monitoring were time

Table 1 Contribution of each exercise intensity zone to the total endurance training time performed in each phase and cycle

	A phase		B phase		C phase	
	A_{TP}	A_{BP}	B_{TP}	B_{BP}	C_{TP}	C_{BP}
Z1	60.7 ± 3.1	17.4 ± 0.8	20.6 ± 0.9	11.9 ± 0.5	9.2 ± 0.3	5.0 ± 0.2
Z2	64.8 ± 2.8	30.0 ± 1.2	27.0 ± 0.9	15.8 ± 0.3	11.1 ± 0.3	4.8 ± 0.1
Z3	9.5 ± 0.5	5.3 ± 0.9	23.4 ± 1.1	21.8 ± 1.0	16.7 ± 0.9	8.6 ± 0.8

Data are expressed in hours as mean ± SD

A_{TP}, B_{TP} and C_{TP}: A, B and C phases of traditional periodization cycle

A_{BP}, B_{BP} and C_{BP}: A, B and C phases of block periodization cycle

Z1: light intensity (below *V*T2), Z2: moderate intensity (between *V*T2 and 90% of VO_{2peak}), Z3: high intensity (between 90 and 100% of VO_{2peak})

Table 2 Description of the endurance training modes used for each intensity zone

Intensity zone	Total volume (min)	Sets	Repetitions	Work period (min)	Rest period (min)	Intensity (%VO_{2peak})
Z1	70–120	1	1–3	20–90	1–3	70–80
Z2	40–90	2–4	1–10	5–20	1–4	80–90
Z3	20–60	2–5	4–8	1–8	2–8	90–100

spent (hours) and distance covered (km) for volume; and heart rate and paddling speed for intensity. Distance and speed were registered by means of a GPS receiver (Garmin 201, Garmin Ltd., USA), and heart rate was monitored using standard HR telemetry (S610i, Polar Electro Oy, Finland).

In addition to endurance training, subjects took part in a concurrent resistance training program during both TP and BP cycles. Athletes performed three strength training sessions per week, consisting mainly of free-weights exercises (including bench press, prone bench pull, pull-ups, full squat and shoulder press). Strength training during both cycles was structured into cycles of 12–17 weeks, during which three types of strength training were sequentially applied: hypertrophy (8–10 repetitions, 4–5 sets, 70–75% 1RM loading intensity, 2-min inter-set rests); maximal strength (3–4 repetitions, 3–4 sets, 85–90% 1RM, 4-min inter-set rests); and maximal power (5–8 repetitions, 4–5 sets, 45–60% 1RM, 4-min inter-set rests). Strength training volume during the 22-week of the TP cycle amounted to 29.5 ± 1.9 h for hypertrophy; 18.2 ± 1.3 h for maximal strength; and 10.4 ± 1.3 h for maximal power. During the 12 weeks of the BP cycle, strength training volume amounted to 16.9 ± 1.0 h for hypertrophy; 12.5 ± 1.3 h for maximal strength; and 6.8 ± 1.3 h for maximal power.

Testing

Kayakers were already familiarized with the testing protocols as they had been assessed on several occasions in previous seasons for training prescription purposes. To assess the selected physiological, performance and anthropometric variables, subjects reported to the laboratory four times during both TP (T_{TP0}, T_{TP1}, T_{TP2} and T_{TP3}) and BP (T_{BP0}, T_{BP1}, T_{BP2} and T_{BP3}) cycles. Testing sessions were performed PRE- and POST- the corresponding training phases of TP and BP cycles (i.e. right after A, B and C phases) (Fig. 1). No strenuous exercise was undertaken 24 h before reporting to the laboratory for testing. The same warm-up procedures and protocol for each type of test were repeated in subsequent occasions. All testing sessions were performed at the same time of day (9–12 h) and under similar environmental conditions (20–22°C and 55–65% humidity). Paddling testing variables showed reliability coefficients ranging from 0.92 to 0.98. The coefficients of variation (CV) for VO_{2peak}, $VT2$, and HR_{peak} ranged between 3.2 and 5.1%. The test–retest intraclass correlation coefficients for all variables used in this study were greater than 0.93 and CV ranged from 0.9 to 2.9%.

Body composition

Anthropometric measurements included: standing height, body mass, skinfold thicknesses (triceps brachii, subscapular, suprailiac, abdominal, anterior thigh, medial calf, supraspinale and biceps brachii), and were performed by the same experienced investigator in accordance with the guidelines from the International Society for the Advancement of Kineanthropometry (ISAK) (Marfell-Jones et al. 2006). Height was measured to the nearest 0.1 cm during a maximal inhalation, and body mass to the nearest 0.1 kg using a calibrated scale (Seca 714, Hamburg, Germany); skinfold thickness was assessed using a skinfold caliper (accurate to 0.2 mm), all from the Harpenden range of anthropometric instruments (Holtain Ltd., UK).

Maximal incremental exercise test

After a 5-min warm-up at a speed of 9 km h^{-1}, subjects completed an incremental paddling test to volitional exhaustion on a kayak ergometer (Dansprint ApS, Denmark; drag resistance coefficient = 35). The first stage was set at a speed of 11.5 km h^{-1} and the speed increments were 0.5 km h^{-1} each minute. Each kayaker was allowed to freely adjust his stroke rate (SR) as needed, while this rate was continuously recorded by means of a stroke counter (Interval 2000, Nielsen-Kellerman, USA). Heart rate (HR) was monitored using standard telemetry (S610i; Polar Electro Oy, Finland) and recorded every 5 s. Paddlers were encouraged to give a maximal effort and to complete as many stages as possible. The test concluded when a subject voluntarily stopped paddling or he was unable to maintain the imposed speed. Breath-by-breath gas analysis was conducted throughout using an automated Jaeger Oxycon Pro system (Erich Jaeger, Germany). The gas analyzers were calibrated using a 4.95% CO_2–95.05% N_2

gas mixture (BOC Gases, Surrey, UK), and the volume sensor using a 3-L calibration syringe.

Physiological variables

VO_{2peak} was defined as the average of the two highest single consecutive 15-s VO_2 mean values attained toward the end of the test. All subjects fulfilled the following two criteria for VO_{2peak} achievement: (1) respiratory exchange ratio greater than 1.1; and (2) peak HR at least equal to 90% of the age-predicted maximum. Second ventilatory threshold ($VT2$) was determined from gas exchange measurements using the criteria of an increase in both ventilatory equivalents ($V_E VO_2^{-1}$ and $V_E VCO_2^{-1}$) and a decrease in the end-tidal carbon dioxide tension ($P_{ET}CO_2$). Two independent and experienced observers made $VT2$ determinations. If there was disagreement between the two, a third observer was brought in. HR at VO_{2peak} (HR_{peak}), and HR at $VT2$ (HR_{VT2}) were also determined for each paddler. Capillary whole blood samples were taken from each kayaker's earlobe during test recovery (min 1, 3, 5, 7, 10 and 12) to determine peak lactate concentration ($[La^-]_{peak}$) using a miniphotometer (LP20; Dr. Lange, France).

Kayaking performance variables

Paddling variables that play a key role in kayaking performance were measured during the maximal exercise test: paddling speed at VO_{2peak} (PS_{peak}), paddling speed at $VT2$ (PS_{VT2}), stroke rate at VO_{2peak} (SR_{peak}), stroke rate at $VT2$ (SR_{VT2}), paddling power at VO_{2peak} (Pw_{peak}), and paddling power at $VT2$ (Pw_{VT2}).

Statistical analyses

The Shapiro–Wilk test was applied to determine the nature of the data distribution. Because normal distribution was not confirmed, Mann–Whitney U and t test were used to evaluate changes in selected variables over the two cycles. Friedman was applied to evaluate changes in the four tests and in the two cycles. Wilcoxon post hoc corrected the significance level according to Bonferroni. Effect sizes (ES) for changes in both training models (TP and BP) between T0 and T1, T1 and T2, T2 and T3 as well as between T0 and T3 time points were calculated as the difference between the means divided by the average standard deviation for the two groups. Significance was accepted at $P \leq 0.05$ level. Statistical power calculations for this study ranged from 0.75 to 0.81.

Results

At baseline of S1 and S2 (i.e. T_{TP0} and T_{BP0}), no significant differences were observed for any of the following variables: VO_{2peak}, VO_2VT2, $[La^-]_{peak}$, HR_{peak}, HR_{VT2}, PS_{peak}, PS_{VT2}, Pw_{peak}, Pw_{VT2}, SR_{peak}, SR_{VT2}, body mass and sum of eight skinfolds.

Body composition

Between T0 and T3, significant group × time interaction was observed for sum of eight skinfolds, with a significantly larger ($P < 0.05$) magnitude of decline for TP (−17.9%, $P < 0.05$, ES = −2.98) as compared to BP (−5.4%, $P < 0.05$, ES = 2.64). Significant declines ($P < 0.05$) in sum of eight skinfolds were detected after A_{TP} (−18.1%, ES = −3.07) and B_{BP} (−16.8%, ES = −2.59), as well as significant increases ($P < 0.05$) following C_{TP} (9.3%, ES = 1.10) and C_{BP} (21.2%, ES = 2.65) phases. No significant changes were detected in body mass at any time point during both cycles (Table 3).

Table 3 Changes in anthropometric variables during the two training cycles

	TP cycle				BP cycle			
	T_{TP0}	T_{TP1}	T_{TP2}	T_{TP3}	T_{BP0}	T_{BP1}	T_{PB2}	T_{BP3}
Body mass (kg)	86.5 ± 4.4	87.1 ± 3.9	86.0 ± 3.7	86.2 ± 4.0	85.7 ± 4.4	87.7 ± 4.8	85.4 ± 4.5	85.2 ± 4.6
Sum 8 skinfolds (mm)	71.4 ± 4.1	58.5 ± 4.3*	53.6 ± 4.6	58.6 ± 4.5$^{£\dagger}$	67.1 ± 5.1	63.0 ± 4.3	52.4 ± 3.9$^{\#}$	63.5 ± 4.5$^{£\beta}$

Data are mean ± SD

Skinfolds: triceps brachii, subscapular, suprailiac, abdominal, anterior thigh, medial calf, supraspinale and biceps brachii

* $P < 0.05$ when comparing T_{TP0} to T_{TP1} and T_{BP0} to T_{BP1}

$^{\#}$ $P < 0.05$ when comparing T_{TP1} to T_{TP2} and T_{BP1} to T_{BP2}

$^{£}$ $P < 0.05$ when comparing T_{TP2} to T_{TP3} and T_{BP2} to T_{BP3}

† $P < 0.05$ when comparing T_{TP0} to T_{TP3} and T_{BP0} to T_{BP3}

$^{\beta}$ $P < 0.05$ when comparing T_{TP3} to T_{BP3}

Physiological changes

Both TP and BP cycles resulted in similar gains in VO_{2peak} (11.0%, ES = 2.09 and 8.1%, ES = 2.30, respectively, $P < 0.05$) and VO_2VT2 (9.8%, ES = 1.79 and 9.4%, ES = 2.00, respectively $P < 0.05$). Significant increases in VO_{2peak} were detected from T_{TP0} to T_{TP1} (4.9%, $P < 0.05$, ES = 1.15), whereas lower, non-significant, increases were observed between T_{BP0} and T_{BP1} (3.4%; $P = 0.08$, ES = 0.86). Following B_{TP} and B_{BP} phases, VO_{2peak} increased significantly in both cycles (7.0%, ES = 1.58 and 5.0%, ES = 1.25, respectively, $P < 0.05$). No significant changes in VO_{2peak} were detected between T2 and T3 in any group. The magnitude of changes in VO_2VT2 was similar after A_{TP} (15.3%, $P < 0.05$, ES = 2.89) and A_{BP} phases (10.7%, $P < 0.05$, ES = 2.57). In addition, significant declines in VO_2VT2 were observed after B_{BP} (−3.9%, $P < 0.05$, ES = −0.69) and B_{TP} phases (−3.4%, $P = 0.06$, ES = −0.98). No significant changes were detected after C_{TP} and C_{BP} phases in VO_2VT2 values. At T3, no significant differences were detected in $VT2$ ($\%VO_{2peak}$) values between both training cycles. The magnitude of changes in $VT2$ ($\%VO_{2peak}$) was similar after A_{TP} (9.9%, $P < 0.05$, ES = 4.37) and A_{BP} (8.0%, $P < 0.05$, ES = 2.1) phases, as well as following both B_{TP} (−9.7%, $P < 0.05$, ES = −2.74) and B_{BP} phases (−8.5%, $P < 0.05$, ES = −2.96).

Kayaking performance changes

Significant increases ($P < 0.05$) in PS_{peak} values were detected following A_{TP} (2.1%, ES = 1.00), A_{BP} (2.1%, ES = 1.00) and C_{BP} phases (2.0%, ES = 0.86), whereas lower increases were found after the B_{BP} phase (2.0%, $P = 0.06$, ES = 0.86). Between T0 and T3, significant group × time interaction was observed for PS_{peak}, with a significantly larger ($P < 0.05$) magnitude of increase for the BP (6.2%, ES = 3.00) as compared to the TP (3.4%, ES = 1.25) cycle. The magnitude of increase in PS_{VT2} between T0 and T3 was similar after TP (5.2%, $P < 0.05$, ES = 2.80) and BP (4.4%, $P < 0.05$, ES = 2.40) cycles. Significant increases ($P < 0.05$) were observed in PS_{VT2} after both A_{TP} (2.2%, ES = 1.00) and A_{BP} (2.2%, ES = 1.50) phases, whereas it remained unchanged after the B and C phases of both cycles.

Between T0 and T3, significant group × time interaction was observed in Pw_{peak}, with a significantly larger ($P < 0.05$) magnitude of increase for BP (14.2%, ES = 6.00) compared to TP (8.3%, ES = 4.00). Significant increases ($P < 0.05$) in Pw_{peak} values were detected following A_{TP} (5.0%, ES = 2.31), A_{BP} (6.8%, ES = 1.27), and C_{BP} phases (5.5%, ES = 2.8). The magnitude of increase in Pw_{VT2} between T0 and T3 was similar after TP (11.3%, $P < 0.05$, ES = 4.67) and BP (10.0%, $P < 0.05$, ES = 3.80). Significant increases ($P < 0.05$) in Pw_{VT2} were detected following A_{TP} (5.3%, ES = 2.22) and A_{BP} (5.8%, ES = 1.69) phases. At T3, SR_{peak} showed significantly ($P < 0.05$) lower values for the BP as compared to the TP cycle. SR_{peak} increased significantly ($P < 0.05$) after the C_{TP} phase (5.9%, ES = 0.92), whereas it remained unchanged after C_{BP}.

No other significant differences at any time point were observed for the rest of the physiological and performance variables analyzed (HR_{peak}, HR_{VT2}, SR_{VT2}, and $[La^-]_{peak}$), although certain trends towards lower values of HR_{VT2}, SR_{peak} and SR_{VT2} after both A_{TP} and A_{BP} phases ($P < 0.1$) were found (Table 4).

Discussion

The main finding of the present study was that a block periodized (BP) training cycle seemed to be more effective than traditional periodization (TP) for improving the performance of highly trained top-level kayakers because: (1) both TP and BP cycles resulted in similar gains in VO_{2peak} and VO_2VT2, even though the TP cycle was 10 weeks and 120 h longer than the BP cycle; and (2) training-induced increases in PS_{peak} and Pw_{peak} (i.e., specific paddling performance) were significantly greater following BP as compared to TP.

The most important differences between both cycles were the total training volume (i.e. endurance training hours) and the percentage of training volume developed over the selected endurance training targets. During both initial 'A' phases, the main goal was to increase the exercise intensity corresponding to the $VT2$, whereas during 'B' phases, the objective was to improve maximal aerobic power (VO_{2max}) (Fig. 1). Our data indicate that during the BP design paddlers completed a greater workload accumulation over the selected training targets while performing a lower total training volume per intensity zone and per phase than during the TP approach (Table 1). An important finding of the present study was that although the total endurance training time completed in the BP cycle was 50% of that performed in the TP cycle, similar training-induced effects in most of the physiological and performance variables studied were found. VO_{2peak} levels significantly increased following A_{TP} and A_{BP} phases (4.9 and 3.5%, respectively), even though the development of VO_{2max} was not the main goal during these phases and training intensity was kept relatively low (Z1 and Z2 zones). These improvements in VO_{2peak} were likely due to the relatively low initial endurance level exhibited by the athletes as a consequence of the previous 5-week transition period. A decrease in maximal aerobic power after several

Table 4 Changes in selected physiological and kayaking performance variables during the two training cycles

	Traditional periodization cycle				Block periodization cycle			
	T_{TP0}	T_{TP1}	T_{TP2}	T_{TP3}	T_{BP0}	T_{BP1}	T_{PB2}	T_{BP3}
VO_{2peak} (mL kg^{-1} min^{-1})	61.1 ± 2.7	64.1 ± 2.5*	68.6 ± 3.2$^{\#}$	67.8 ± 3.7†	62.0 ± 2.2	64.1 ± 2.7	67.3 ± 2.4$^{\#}$	68.1 ± 3.1†
VO_2VT2 (mL kg^{-1} min^{-1})	50.8 ± 2.4	58.6 ± 3.0*	56.6 ± 2.8	55.1 ± 2.4†	50.2 ± 2.3	56.1 ± 2.3*	53.9 ± 2.2$^{\#}$	54.9 ± 2.4†
$VT2$ (%VO_{2peak})	83.1 ± 1.1	91.4 ± 2.7*	82.5 ± 3.8$^{\#}$	81.3 ± 1.7	81.0 ± 3.4	87.5 ± 2.8*	80.1 ± 2.2$^{\#}$	80.6 ± 3.0
PS_{peak} (km h^{-1})	14.5 ± 0.3	14.8 ± 0.3*	15.0 ± 0.3	15.0 ± 0.5†	14.5 ± 0.3	14.8 ± 0.3*	15.1 ± 0.4	15.4 ± 0.3$^{£\dagger\beta}$
PS_{VT2} (km h^{-1})	13.5 ± 0.2	13.8 ± 0.4*	14.1 ± 0.2	14.2 ± 0.3†	13.6 ± 0.2	13.9 ± 0.2*	14.1 ± 0.2	14.2 ± 0.3†
Pw_{peak} (W)	220 ± 5	231 ± 7*	237 ± 5	240 ± 5†	218 ± 6	233 ± 7*	240 ± 4	254 ± 6$^{£\dagger\beta}$
Pw_{VT2} (W)	186 ± 4	196 ± 5*	205 ± 5	207 ± 5†	191 ± 6	202 ± 7*	207 ± 4	210 ± 4†
$[La^{-}]_{peak}$ (mmol L^{-1})	11.5 ± 4.9	11.9 ± 3.2	10.5 ± 3.5	11.7 ± 3.1	11.2 ± 3.7	12.7 ± 3.1	12.7 ± 3.4	12.0 ± 2.6
HR_{peak} (beats min^{-1})	190 ± 9	187 ± 11	188 ± 9	189 ± 4	193 ± 8	189 ± 7	189 ± 10	189 ± 7
HR_{VT2} (beats min^{-1})	176 ± 7	172 ± 8	172 ± 7	176 ± 9	175 ± 6	172 ± 6	171 ± 6	173 ± 7
SR_{peak} (strokes min^{-1})	106 ± 4	102 ± 7	102 ± 8	108 ± 5$^{£}$	104 ± 4	101 ± 8	102 ± 7	103 ± 8$^{\beta}$
SR_{VT2} (strokes min^{-1})	86 ± 4	84 ± 3	84 ± 5	87 ± 6	87 ± 5	84 ± 6	86 ± 5	85 ± 6

Data are mean ± SD

* $P < 0.05$ when comparing T_{TP0} to T_{TP1} and T_{BP0} to T_{BP1}

$^{\#}$ $P < 0.05$ when comparing T_{TP1} to T_{TP2} and T_{BP1} to T_{BP2}

$^{£}$ $P < 0.05$ when comparing T_{TP2} to T_{TP3} and T_{BP2} to T_{BP3}

† $P < 0.05$ when comparing T_{TP0} to T_{TP3} and T_{BP0} to T_{BP3}

$^{\beta}$ $P < 0.05$ when comparing T_{TP3} to T_{BP3}

weeks of training cessation has been reported for endurance athletes (Coyle et al. 1984; García-Pallarés et al. 2009b, 2010; Mujika and Padilla 2000). Thus, after resuming formal training, it seems logical that part of the aerobic fitness level was quickly regained, regardless of the training intensities and methods used. Following 'B' phases, VO_{2peak} increased by 7.0% in TP and 5.3% in BP, after 33% (23.4 h) and 44% (21.8 h) of total endurance training volume performed in Z3, respectively. In this periodization phase, it should be noted that the B_{BP} was more effective than the B_{TP} phase for the development of VO_{2max}, because paddlers achieved similar performance increases, but using lower training volume. The increases in VO_{2peak} observed in the present study (i.e. 9.5 and 11.0% following the 12-week BP cycle and 22-week TP cycle, respectively) were greater than those previously described for international-level kayakers and canoeists. For instance, Tesch et al. (1976), in a longitudinal study with top-level paddlers, reported increases around 8.0% in VO_{2max}, although these were accomplished after a considerably longer training period (8 months).

On the other hand, the training workloads performed by paddlers during both 'C' phases were only effective to maintain the VO_{2peak} levels achieved at the end of the previous 'B' phases and no further gains were detected. This finding is in agreement with those of Houmard et al. (1994), Shepley et al. (1992) and Van Handel et al. (1988) who observed a stable VO_{2max} following 7–20 days of tapering in highly trained athletes. Furthermore, the lack of further increases in VO_{2peak} after both tapering phases (C_{TP} and C_{BP}) may be related to the high-performance level of the athletes, with VO_{2peak} means of 67.8 and 68.1 mL kg^{-1} min^{-1} reached at the end of both training cycles. These VO_{2peak} values were significantly higher than those obtained in other studies with high-level kayakers (mostly in the range of 54–60 mL kg^{-1} min^{-1}) (Bishop et al. 2002; Fry and Morton 1991; Tesch et al. 1983; Van Someren and Oliver 2002).

Significant increases of ~15% in VO_2VT2 were found following A_{TP} (64.8 h and 48% of total endurance training time in Z2) and A_{BP} (30.0 h and 57% of Z2 training). Since paddlers achieved similar increases in this variable, but using 50% less endurance training volume in Z2, BP seemed to be more effective for developing the $VT2$ than TP. During B_{TP} and B_{BP} phases, coincident with an important reduction in total endurance training time in Z2 (only 38 and 32%, respectively), VO_2VT2 values decreased by 3.4 and 4.3% in the TP and BP cycles, respectively. These data seem to indicate that training volume around the $VT2$ (Z2) was insufficient, especially during the BP cycle. These results are in agreement with those described by Hickson et al. (1982) who found no changes in VO_{2max} levels and significant declines in time to exhaustion at 80% of VO_{2max} after a 5-week reduction in training volume in well-trained subjects. Furthermore, the duration of the residual training effects seems to be related to factors such as an athlete's performance level and the amount of training performed on other physical/motor abilities. From

a practical standpoint, and during either a TP or BP cycle, it would seem adequate to introduce short periods (2–3 days) of high training workload over motor abilities developed in previous phases to maintain their residual training effects. During both 'C' phases VO_{2peak} and $VT2$ levels remained unchanged; thus, both tapering phases prescribed in the present training approach (C_{TP} and C_{BP}) seemed to be effective to maintain the athletes' performance at $VT2$ level until the end of the cycle.

The similar trends detected in body mass and sum of eight skinfolds following both TP and BP training cycles suggest that these two different periodization designs did not produce different changes in the paddlers' body composition. It should be noted that following the first two training phases of both cycles (i.e. '*A*' and '*B*') body mass remained unchanged while body fat decreased progressively. Sum of eight skinfolds was significantly lower following A_{TP} than A_{BP}, probably as a consequence of the much longer (12 vs. 5 weeks) 'A' phase in the TP cycle. Following both 'C' phases body mass remained unchanged, but sum of eight skinfolds increased significantly, probably due to the drastic reduction in total training volume and absence of control over the athletes' diet during this tapering phase.

Training-induced changes in kayaking performance variables (PS_{peak}, PS_{VT2}, Pw_{peak} and Pw_{VT2}) were different following both periodization models. The BP cycle led to significant increases in PS_{peak} and Pw_{peak} between the consecutive phases analyzed, whereas the TP cycle showed significant improvements only when the initial and final tests (T0 vs. T3) were compared. Moreover, at the end of both cycles, BP led to significantly better results than those found after TP for PS_{peak} and Pw_{peak} (15.4 km h^{-1} and 254 W in T_{BP3} vs. 15.0 km h^{-1} and 240 W in T_{TP3}). Following the BP model, the tapering-related increases of 2% in PS_{peak} and 4.5% in paddling power at VO_{2peak} were similar to the performance improvements observed in previous studies after tapering phases of 1–4 weeks in highly trained swimmers, cyclists and distance runners (Houmard et al. 1994; Mujika et al. 1996, 2002; Neary et al. 2003). In contrast, the tapering phase of the TP cycle (C_{TP}) only allowed the maintenance of the previously training-induced changes in Pw_{peak}, together with an increase in SR_{peak}. These unexpected results after C_{TP} could be related to a loss of the paddlers' capacity to apply force in each paddling stroke. Thus, an increased stroke rate would be needed to maintain the required paddling power output and/or boat speed. These data are in agreement with a recent study that reported similar increases in stroke rate following 5 weeks of training cessation in top-level kayakers (García-Pallarés et al. 2009b). Therefore, a tapering phase subsequent to a BP cycle may also lead to greater improvements of kayaking performance (i.e. Pw_{peak} and SR_{peak}) as compared to that performed after a TP cycle. Taken together, these data suggest that BP was more effective than TP to avoid the loss of the residual training effects and to achieve a greater kayaking performance peak during the tapering phase in highly trained athletes.

Lastly, although it is very difficult to make comparisons of kayaking performance during testing and competition due to the great number of confounding variables that considerably affect split times (e.g. wind speed and direction, water temperature and salinity, depth, currents), it is interesting to note that the results during competitions at the main events of the respective seasons were also very different between cycles. Thus, after the traditional training approach (2006–2007 season), none of the athletes qualified for the Beijing Olympics during the 2007 World Championships. However, during the 2007–2008 season, following a BP training design, four members of the team achieved the qualification for the Olympic Games and, more importantly, a few months later two of them won the Olympic gold medal.

In summary, short training phases (5 week) following a BP model using half the total training volume, but with a ~10% higher workload accumulation over the selected training targets (45–60% of total training volume) for each phase resulted in a more effective training stimulus for the improvement of kayaking performance when compared with a TP model in elite-level paddlers. The results of the present study also suggest that, following a tapering phase, a BP design could be a more useful strategy to maintain the residual training effects on SR_{peak} as well as to achieve greater improvements in certain variables related to kayaking performance (i.e. Pw_{peak} and SR_{peak}).

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