

Research article

Post-season detraining effects on physiological and performance parameters in top-level kayakers: comparison of two recovery strategies

Jesús García-Pallarés ¹✉, Luis Carrasco ², Arturo Díaz ¹ and Luis Sánchez-Medina ³

¹ Faculty of Sport Sciences, University of Murcia, Spain, ² Department of Physical Education and Sport, University of Seville, Spain, ³ Faculty of Sport, Pablo de Olavide University, Seville, Spain

Abstract

This study analyzed changes in physiological parameters, hormonal markers and kayaking performance following 5-wk of reduced training (RT) or complete training cessation (TC). Fourteen top-level male kayakers were randomly assigned to either a TC (n = 7) or RT group (n = 7) at the end of their competitive season (T1). Subjects undertook blood sampling and an incremental test to exhaustion on a kayak ergometer at T1 and again following 5 weeks of RT or TC (T2). Maximal oxygen uptake (VO_{2max}) and oxygen uptake at second ventilatory threshold (VT2) significantly decreased following TC (-10.1% and -8.8%, respectively). Significant decreases were also observed in RT group but to a lesser extent (-4.8% and -5.7% respectively). Heart rate at VT2 showed significant increases following TC (3.5%). However, no changes, were detected in heart rate at VO_{2max} in any group. Peak blood lactate remained unchanged in both groups at T2. Paddling speed at VO_{2max} declined significantly at T2 in the TC group (-3.3%), while paddling speed at VT2 declined significantly in both groups (-5.0% and -4.2% for TC and RT, respectively). Stroke rate at VO_{2max} and at VT2 increased significantly only following TC by 5.2% and 4.9%, respectively. Paddling power at VO_{2max} and at VT2 decreased significantly in both groups although the values observed following RT were higher than those observed following TC. A significant decline in cortisol levels (-30%) was observed in both groups, while a higher increase in testosterone to cortisol ratio was detected in the RT group. These results indicate that a RT strategy may be more effective than complete TC in order to avoid excessive declines in cardiovascular function and kayaking performance in top-level paddlers.

Key words: Detraining; aerobic power; kayaking; paddling parameters; hormonal profile.

Introduction

Training periodization for competitive athletes emphasizes the need to incorporate a period of regeneration following the conclusion of the main event of the season in order to allow physical and mental recovery before the beginning of a new training cycle (Bompa, 1999; Issurin, 2008). However, the consequences that typical post-season breaks of 4-6 wk could have on physiological and performance markers of top-level athletes are not completely understood. The magnitude of the performance decline observed following a period of detraining appears to be related to the chosen recovery strategy (reduced training or complete training cessation), initial fitness level, and total time under

reduced or absence of training stimuli (Mujika and Padilla, 2000a; 2000b).

These recovery periods are initially characterized by marked alterations in the cardiorespiratory, neuromuscular and metabolic systems that may induce a detraining state (Mujika and Padilla, 2001). Numerous studies have reported VO_{2max} declines between 6-14% in well-trained athletes who refrained from training for 3-6 wk (Coyle et al., 1984; Martin et al., 1986; Petibois and Délérís, 2003), while less pronounced declines in VO_{2max} have been detected following shorter TC periods (Houston et al., 1979; Houmard et al., 1992). By contrast, in recreationally-trained individuals, residual training effects seem more readily retained. Thus, no significant changes in VO_{2max} following 3-wk of TC (Moore et al., 1987) or a small decrease (~7%) following 4-6 wk of TC (Hansen et al., 2004; Marles et al., 2007) have been reported for these population groups, respectively. The declines observed in maximal aerobic power following periods of complete training cessation appear to be related to decreases in basic cardiorespiratory parameters such as blood volume, cardiac output, stroke volume, and maximal voluntary ventilation (Cullinane et al., 1986; Martin et al., 1986).

Skeletal muscle tissue is not an exception to these detraining effects. Reductions in capillary density (Houston et al., 1979), oxidative capacity (Mujika and Padilla, 2001), mean fiber cross-sectional area (Bangsbo and Mizuno, 1988), EMG activity (Häkkinen et al., 1981), maximal arterio-venous VO_2 difference (Coyle et al., 1984), and fiber type changes (Larsson and Ansved, 1985) have all been documented in athletes following periods of TC.

In an attempt to reduce the negative impact that the absence of training stimuli may have on athletic performance, training reduction strategies (periods during which volume and/or training intensity are significantly reduced) have been proposed as an alternative to complete training cessation, especially for elite level athletes (Neufer et al., 1987; Mujika and Padilla, 2000a; 2000b). However, there is a relative lack of information on the effects of RT on physiological parameters and athletic performance. Few investigations (Hickson et al., 1982; Neufer et al., 1987) have been carried out in order to determine the detraining effects caused by a RT approach. These studies show that it is possible to drastically reduce total volume and/or frequency of training during 4-wk and still maintain VO_{2max} levels. However, although a single high-intensity 35-min weekly session was effective to maintain VO_{2max} in a group of well-trained endurance athletes, endurance

capacity (defined as maximal time to exhaustion at 75% of VO_{2max}) decreased by 20% following 4-wk of this type of training (Madsen et al., 1993).

On the other hand, it is generally recognized that training and competing at the elite level induces considerable stress on the neuroendocrine system. The interplay between anabolic and catabolic processes, that takes place as a consequence of exercise and recovery, plays a vital role in mediating the physiological adaptations to physical training (Kraemer and Ratamess, 2005). Short-term TC or RT periods have shown increased resting concentrations of anabolic (e.g. testosterone, growth hormone) and declines in catabolic (e.g. cortisol) hormones, possibly related to the body's improved ability to combat the catabolic processes and enhanced tissue remodelling and repair (Hortobágyi et al., 1993). However, the hormonal response of elite athletes from sports with great demands of both strength and endurance (e.g. Olympic kayaking) following periods of TC or RT remains unclear.

To our knowledge, there are no studies that have compared the effects of a TC versus a RT strategy on physiological and performance variables in athletes of a truly high-calibre during a post-season recovery period. Therefore, the aim of this study was to examine changes in physiological parameters, hormonal markers and kayaking performance following 5-wk of either RT or complete TC in a group of world-class kayakers.

Methods

Participants

Fourteen top-level flat-water male kayak paddlers (including ten World Championship finalists, and two olympic gold-medallists) volunteered to take part in this study. Characteristics of participants (mean \pm SD) were as follows: age 25.2 ± 2.5 yr, body mass 84.0 ± 5.5 kg, height 1.81 ± 0.04 m; training experience 11.1 ± 2.7 yr, annual paddling volume $4,415 \pm 374$ km. Paddlers had at least two 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.

Previous training

The training season comprised a total of 47-wk that ended with the Flatwater Racing World Championship. During this period, paddlers undertook a periodized training program of combined strength and endurance training, under the guidance and supervision of professional canoeing coaches. Strength training volume during these 47-wk amounted to: 37.8 ± 2.6 h, 42 ± 3 sessions, 840 ± 60 sets and $7,560 \pm 540$ repetitions for hypertrophy; 44.4 ± 3.2 h, 42 ± 3 sessions, 642 ± 46 sets and $2,600 \pm 199$ repetitions for maximal strength; and 32.4 ± 1.1 h, 34 ± 2 sessions, 488 ± 29 sets and $2,673 \pm 158$ repetitions for maximal power. Endurance training was structured into 3 cycles of 11-22 wk duration. Total endurance training volume was 264.1 ± 12.7 h at paddling speeds corresponding to 75-

90% VO_{2max} , 39.9 ± 2.0 h between 90-105% VO_{2max} , and 8.6 ± 0.6 h above 105% VO_{2max} and required athletes to paddle 60-130 km, distributed in 10-15 kayaking sessions per week.

Experimental design

All subjects underwent a maximal incremental exercise test 25-d before the start of the World Championship (T1) in order to avoid any interference with the paddlers' preparation for this competition, the most important event of the season. Blood tests were performed 5-d before the event. The same assessments were held again 5-wk following the conclusion of the World Championship (T2). Following this competition, each participant was randomly assigned to a reduced training (RT; $n = 7$) or training cessation (TC; $n = 7$) group. The TC group fully discontinued any physical training during the following 5 weeks, whereas the RT group performed only one resistance training and two endurance training sessions per week. The resistance training session (Wednesday) comprised 3 sets of 10 repetitions with each athlete's 12RM load in the bench press, prone bench pull and squat exercises, using pauses of 3 min between sets. Endurance training consisted of only two 40-min moderate-intensity ($\sim 80\%$ VO_{2max}) running (Monday) and paddling sessions (Friday), respectively. On the four remaining week days no physical training of any kind was performed. During each of these 5-wk of RT, paddlers completed approximately 20% of the mean weekly training volume completed during the 47 preceding weeks.

Maximal incremental exercise test

Following a 5 min warm-up at a speed of $9 \text{ km}\cdot\text{h}^{-1}$, 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 $11.5 \text{ km}\cdot\text{h}^{-1}$ and the speed increments were $0.5 \text{ km}\cdot\text{h}^{-1}$ 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_{2max} was defined as the average of the two highest single consecutive 15 s VO_2 mean values attained during the last 90 seconds of the test. All subjects fulfilled the following two criteria for VO_{2max} achievement: a) respiratory exchange ratio greater than 1.1; and b) 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 ($V_E \cdot VO_2^{-1}$ and $V_E \cdot VCO_2^{-1}$) 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_{2max} (HR_{max}), 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_{2max} (PS_{max}), paddling speed at VT2 (PS_{VT2}), stroke rate at VO_{2max} (SR_{max}), stroke rate at VT2 (SR_{VT2}), paddling power output at VO_{2max} (PW_{max}), and paddling power output at VT2 (PW_{VT2}).

Blood collection and analyses

At T1 and T2, venous blood samples (10 mL) were obtained from an antecubital vein using vacutainers and sterile needles. All samples were obtained at the same time of day for each participant (8-9 h), following a 12 h overnight fast and a previous resting day. Blood samples were collected in tubes containing EDTA, centrifuged at 800 g for 10 min at 4°C, and plasma stored at -80°C until assayed in duplicate for total testosterone (T) and cortisol (C) by radioimmunoassay (125I RIA kits, DiaSorin, MN, USA). The intra- and inter-assay variances for T were less than 3.5% and 7.0%, respectively; whereas intra- and inter-assay variances for C were less than 4.6% and 5.8%, respectively.

Statistical analysis

Standard statistical methods were used for the calculation of means and standard deviations (SD). A two-way

ANOVA was performed in order to evaluate absolute changes in selected variables between time points (T1, T2) and between groups (TC, RT). Significance was accepted at the $p < 0.05$ level.

Results

Physiological variables

No significant differences were found at T1 between groups for any physiological variable. Following the 5-wk post-season break, VO_{2max} declined by -11.3% (from 69.1 ± 3.9 to 61.3 ± 2.7 mL·kg⁻¹·min⁻¹; $p < 0.01$) and -5.6% (from 68.5 ± 3.0 to 64.6 ± 3.1 mL·kg⁻¹·min⁻¹; $p < 0.05$) for the TC and RT groups, respectively. VO_{2max} values at T2 were significantly higher for the RT group compared to those of the TC group. VO_2 at VT2 decreased both in the TC (-8.8%, $p < 0.01$) and RT groups (-5.7%, $p < 0.05$) (Figure 1). HR_{VT2} increased in the TC group from T1 to T2 (+3.5%, $p < 0.05$). Significantly higher values ($p < 0.05$) for HR_{VT2} at T2 were found for the TC when compared with the RT group. No significant differences were observed in VT2 (% VO_{2max}), HR_{max} , and $[La^-]_{peak}$ between T1 and T2 for the TC or RT groups (Table 1).

Kayaking performance variables

From T1 to T2, PS_{VT2} declined in both TC (-5.0%) and RT (-4.2%) groups ($p < 0.05$), whereas PS_{max} decreased significantly only in the TC group (-3.3%, $p < 0.05$). SR_{max} and SR_{VT2} demonstrated significant increases only in the TC group (+5.2% and +4.9%, $p < 0.05$, respectively). PW_{max} showed no differences between groups at T1. However, following the 5-wk detraining period, PW_{max} decreased significantly in both groups (-7.9% and -3.9%, $p < 0.05$, for TC and RT respectively). Additionally, the final values attained at T2 were significantly higher ($p < 0.05$) for the RT compared to the TC group. From T1 to T2, the magnitude of decrease in PW_{VT2} (-11%, $p < 0.05$) was identical for both TC and RT groups. Values at T1 and T2 for this variable were

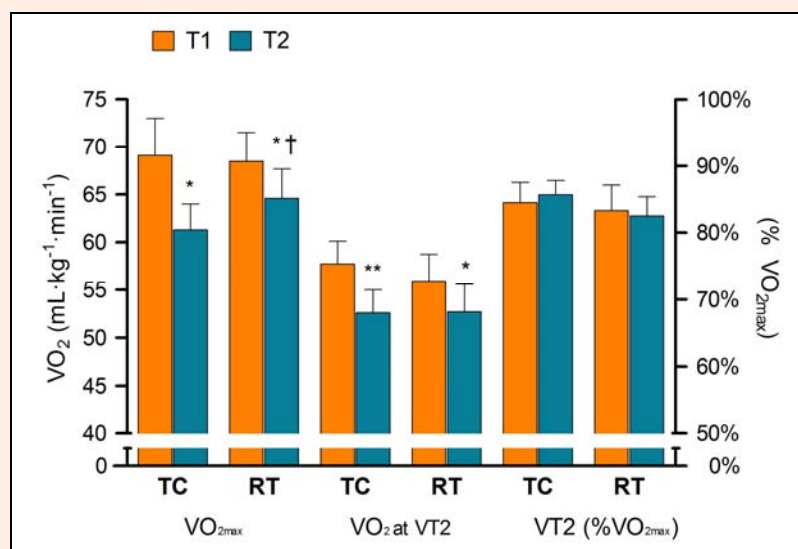


Figure 1. Changes in VO_{2max} , VO_2 at VT2 and VT2 (% VO_{2max}) following a 5-wk period of either training cessation (TC) or reduced training (RT). * $p < 0.05$ compared to T1; ** $p < 0.01$ compared to T1; † $p < 0.05$ compared to TC.

Table 1. Changes in cardiorespiratory and kayaking performance variables. Data are mean (\pm SD).

	TC		RT	
	T1	T2	T1	T2
HR _{max} (beats·min ⁻¹)	193 (6)	195 (6)	189 (7)	192 (5)
HR _{VT2} (beats·min ⁻¹)	173 (5)	179 (4) *	171 (4)	174 (4) †
[La ⁻] _{peak} (mmol·L ⁻¹)	14.0 (3.3)	15.6 (4.6)	13.1 (3.1)	14.0 (3.4)
PS _{max} (km·h ⁻¹)	15.1 (.5)	14.6 (.2) *	15.2 (.3)	14.9 (.3)
PS _{VT2} (km·h ⁻¹)	14.1 (.3)	13.4 (.3) *	14.2 (.3)	13.6 (.2) *
SR _{max} (strokes·min ⁻¹)	96 (3)	101 (3) *	98 (5)	101 (3)
SR _{VT2} (strokes·min ⁻¹)	81 (4)	85 (4) *	83 (5)	85 (4)
PW _{max} (W)	238.4 (6.9)	219.6 (4.0) **	240.9 (6.6)	231.4 (4.4) **†
PW _{VT2} (W)	204.1 (5.8)	182.1 (5.3) **	211.4 (4.4) †	187.9 (6.7) **†

TC: Training Cessation (n = 7); RT: Reduced Training (n = 7). * and ** denote p < 0.05 and 0.01, respectively, compared with T1. † p < 0.05 compared with TC.

significantly higher (p < 0.05) for the RT compared to the TC group (Table 1).

Resting hormones

From T1 to T2, similar decreases (-30%, p < 0.01) were detected in cortisol levels for the TC and RT groups (Table 2). Although testosterone concentration similarly increased from T1 to T2 in both groups, these changes were not statistically significant. T:C ratio markedly increased (p < 0.01) in both TC (+62.5%) and RT groups (+67.6%), with values at T2 being significantly higher for RT than for TC (p < 0.05).

Discussion

The present study indicates that performing a 5 week period of RT in a group of elite kayakers is an effective strategy to minimize the large declines in cardiorespiratory and kayaking performance parameters that take place when training is completely stopped for an equivalent period of time. In addition, a period of short-term detraining such as the one used in this study seems to enhance the body's anabolic state by drastically decreasing resting cortisol levels and moderately increasing testosterone concentrations in both RT and TC groups. Although the RT approach used in this study seemed to be more effective than complete TC to limit the magnitude of declines in aerobic power and endurance capacity, our results show that performing only two short, moderate-intensity endurance training sessions per week during 5-wk is not a sufficient stimulus to prevent significant declines in aerobic performance in highly trained athletes. In line with the results of our study, previous research indicated that maintaining a sufficiently high training intensity during periods of RT and tapering is of paramount importance in order to retain training adaptations (Neufer, 1989).

The declines in maximal aerobic power observed in the TC group (-11%) were similar to those found by other studies that examined highly trained athletes using

similar short-term TC periods (Coyle et al., 1984; Godfrey et al., 2005; Martin et al., 1986; Petibois and Délérís, 2003). By contrast, performing two weekly endurance training sessions at moderate intensity (~80% VO_{2max}) allowed athletes from the RT group to significantly reduce the decrease in VO_{2max} levels experienced by their TC counterparts. This finding is in agreement with those found by other authors who also studied changes in physiological parameters of well trained athletes following periods of markedly reduced training. Thus, following a complete training season, Neufer et al. (1987) found that 4-wk RT (one-third of habitual daily training volume performed in three weekly sessions) allowed competitive swimmers to preserve part of the residual training effects on maximal aerobic power, something that they could not accomplish with only one session per week. Additionally, Hickson et al. (1982) showed that it is possible to maintain VO_{2max} levels with up to a two-third reduction in training volume.

Our RT approach did not prevent a significant decline in VO₂ at VT2 (-5.7%), although this was lower than that experienced by the TC group (-8.8%). These findings are similar to those of Godfrey et al. (2005) who found declines of ~5% in VO₂ at lactate threshold following 8-wk of TC in a male Olympic champion rower. Similarly, Galy et al. (2003) showed that a 6-wk RT period of low volume and intensity of training was enough to maintain VO_{2max} levels but not to avoid significant decreases in VO₂ at VT2 in a group of well trained triathletes.

Fractional utilization of maximal aerobic power, a valid criteria to evaluate aerobic capacity, remained unchanged in both TC and RT groups, likely due to the proportional declines in both VO_{2max} and VO₂ at VT2 during the 5-wk detraining period, a finding that is in accordance with the observations of Godfrey et al. (2005).

The increases of ~3% found in HR_{VT2} in the TC group are similar to those observed in other studies following periods of TC in well trained subjects (Coyle et al., 1986; Houmard et al., 1992; Madsen et al., 1993).

Table 2. Changes in resting hormones. Data are mean (\pm SD).

	TC		RT	
	T1	T2	T1	T2
Cortisol (nmol·L ⁻¹)	486.9 (70.6)	339.0 (53.3) **	460.0 (77.3)	320.8 (58.4) **
Testosterone (nmol·L ⁻¹)	21.6 (3.4)	24.4 (3.1)	23.3 (4.0)	27.1 (5.4)
T:C x 1,000	44.8 (6.6)	72.8 (10.3) **	51.2 (8.9)	85.8 (11.9) ** †

TC: Training Cessation (n = 7); RT: Reduced Training (n = 7). ** denotes p < 0.01 compared with T1. † p < 0.05 compared with TC.

Nevertheless, HR_{max} and HR_{VT2} in our RT group remain unchanged at T2. The increase in submaximal HR following periods of TC seems to be related to the body's attempt to maintain cardiac output during exercise, and to counterbalance reductions in stroke volume (Coyle et al., 1984; Mujika and Padilla 2000a; 2000b; 2001).

The fact that $[La^-]_{peak}$ remained unchanged following both TC and RT is consistent with that described by Marles et al. (2007), who found no changes in $[La^-]_{peak}$ following 6-wk of RT in recently trained subjects. Other published results have showed that LDH activity increases following TC periods (Costill et al., 1985; Claude and Sharp, 1991; Neuffer et al., 1987).

There is very little information in the literature about the effects of TC or RT strategies on kayaking performance parameters during post-season recovery periods. Although our RT strategy was able to avoid significant declines in PS_{max} , it did not prevent decreases close to 4.5% in PS_{VT2} . Madsen et al. (1993) found that time to exhaustion at 75% of VO_{2max} decreased 21% following 4-wk of RT in well trained subjects. Similarly, following 2-wk of TC, Houston et al. (1979) reported that time of effort at a submaximal intensity decreased by 25%; while Petibois and Dél  ris (2003) found reductions in maximal aerobic velocity (~20%) following 5 wk of TC in highly trained rowers.

In the present study, SR_{max} and SR_{VT2} increased significantly only in the TC group, findings that are well in agreement with the observations made by Issurin et al. (1986), who reported increases in stroke rate during a long tapering phase in top-level kayakers. Additionally, Neuffer et al. (1987) detected significant increases in SR at submaximal and maximal intensities following RT in competitive swimmers. The increases in SR observed in the present study may be due to declines in neuromuscular performance as a consequence of the 5-wk detraining period. Thus, it is likely that a paddler's force-generating capacity in each stroke was impaired, this resulting in the need to increase stroke rate in order to maintain the required power output and/or boat speed. However, the significant increases in SR_{max} and SR_{VT2} experienced by the TC group were not sufficient to compensate for the supposed neuromuscular impairment and PS_{max} , PS_{VT2} and PW_{max} decreased to a greater extent in the TC compared to the RT group.

Although the RT strategy allowed to maintain a number of the residual training effects in the present study, PW_{max} and PW_{VT2} demonstrated a significant decline following both RT and TC. These decreases in paddling power indicate that one resistance and two endurance training sessions per week at moderate intensity were clearly insufficient to maintain specific paddling performance in elite kayakers.

Following the detraining period, resting testosterone concentration demonstrated a non-significant increase in the TC (13%) and RT (16%) groups. Alternatively, cortisol levels decreased significantly in both groups (30%). As a result, the T:C ratio drastically increased (Table 2). All these changes in resting hormonal balance following the short-term detraining period are clearly indicative of an increased androgenic-anabolic activity

(Kraemer and Ratamess, 2005), and seem to be related to the body's reaction to combat the catabolic processes induced by the high levels of physical and mental stress placed upon these top-level athletes during the precedent season. The T:C ratio at T2 was significantly higher in the RT compared to the TC group, again suggesting the convenience of incorporating some maintenance training stimuli in the post-season break to avoid the development of catabolic conditions (i.e. muscle atrophy) or to further enhance the body's anabolic environment. The observed increases in testosterone, T:C and reduction in cortisol are in agreement with the results reported by Hortob  gyi et al. (1993) following 14-d of inactivity. By contrast, other researchers detected no changes in resting concentrations of testosterone, cortisol or T:C ratio following 4-12 wk of TC (H  kkinen et al., 1985; Izquierdo et al., 2007; Kraemer et al., 2002). This suggests that the hormonal response following detraining periods appears to be related to the athletes' initial level of conditioning and total time under reduction or cessation of training stimuli. Albeit measurements of only resting serum hormonal concentrations have their limitations, they have been used extensively in resistance training research (Kraemer and Ratamess, 2005), especially in those studies monitoring athletes' training during the off- and competitive seasons. Moreover, we are aware that although the T:C ratio has been a commonly used marker to indicate a potential anabolic or catabolic state in relation to performance, it appears to be an oversimplification (Izquierdo et al., 2006).

Conclusion

In conclusion, a RT strategy comprised of one resistance and two endurance training sessions per week at moderate intensity was effective to attenuate the adverse detraining effects observed following complete training cessation in physiological and kayaking performance variables such as VO_{2max} , HR_{VT2} , T:C ratio, SR_{max} , SR_{VT2} , PS_{max} , PW_{max} , and PW_{VT2} in top-level paddlers. With the ever-increasing number of competitions and rigorous demands of modern sport at the elite level, performing a minimal maintenance training program in the layoff between seasons seem to be an appropriate measure to prevent athletes from experiencing an excessive loss of aerobic performance, as well as to be able to regain fitness more easily in subsequent training cycles.

Acknowledgements

We thank personnel from the Andalusian High-Performance Sports Medicine Center in Seville for their excellent technical help with laboratory apparatus and medical assistance to the athletes. We also acknowledge the dedicated effort, commitment and professionalism of the selected group of kayakers who took part in this research.

References

- Bangsbo, J. and Mizuno, M. (1988) Morphological and metabolic alterations in soccer players with detraining and retraining and their relation to performance. In: *Science and Football: Proceedings of the First World Congress of Science and Football*. Ed: Reilly, B., Lees, A., Davids, K., Murphy, W.J. Liverpool: E&FN Spon. 114-124.
- Bompa, T. (1999) *Periodization: theory and methodology of training*.

- 4th edition. Human Kinetics, Champaign, IL.
- Claude, A.B. and Sharp, R.L. (1991) The effectiveness of cycle ergometer training in maintaining aerobic fitness during detraining from competitive swimming. *Journal of Swimming Research* **7**, 17-20.
- Costill, D.L., Fink, W.J., Hargreaves, M., King, D.S., Thomas, R. and Fielding, R. (1985) Metabolic characteristics of skeletal muscle during detraining from competitive swimming. *Medicine and Science in Sports and Exercise* **17**, 339-343.
- Coyle, E.F., Hemmert, M.K. and Coggan, A.R. (1986) Effects of detraining on cardiovascular responses to exercise: role of blood volume. *Journal of Applied Physiology* **60**, 95-99.
- Coyle, E.F., Martin, W.H., Sinacore, D.R., Joyner, M.J., Hagberg, J.M. and Holloszy, J.O. (1984) Time course of loss of adaptations after stopping prolonged intense endurance training. *Journal of Applied Physiology* **57**, 1857-1864.
- Cullinane, E.M., Sady, S.P., Vadeboncoeur, L., Burke, M. and Thompson, P.D. (1986) Cardiac size and $\text{VO}_{2\text{max}}$ do not decrease after short-term exercise cessation. *Medicine and Science in Sports and Exercise* **18**, 420-424.
- Galy, O., Manetta, J., Coste, O., Maimoun, L., Chamari, K. and Hue, O. (2003) Maximal oxygen uptake and power of lower limbs during a competitive season in triathletes. *Scandinavian Journal of Medicine and Science in Sports* **13**, 185-193.
- García-Pallarés, J., Sánchez-Medina, L., Carrasco, L., Díaz, A., Izquierdo, M. (2009) Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle. *European Journal of Applied Physiology* **106**, 629-638.
- Godfrey, R.J., Ingham, S.A., Pedlar, C.R. and Whyte, G.P. (2005) The detraining and retraining of an elite rower: a case study. *Journal of Science and Medicine in Sport* **8**, 314-320.
- Häkkinen, K., Komi, P.V. and Tesch, P.A. (1981) Effect of combined concentric and eccentric strength training and detraining on force-time, muscle fiber and metabolic characteristics of leg extensor muscles. *Scandinavian Journal of Sports Sciences* **3**, 50-58.
- Häkkinen, K., Alen, M. and Komi, P.V. (1985) Changes in isometric force- and relaxation-time, electromyographic and muscle fiber characteristics of human skeletal muscle during training and detraining. *Acta Physiologica Scandinavica* **125**, 573-585.
- Hansen, A.L., Johnsen, B.H., Sollers, J.J., Stenvik, K. and Thayer, J.F. (2004) Heart rate variability and its relation to prefrontal cognitive function: the effects of training and detraining. *European Journal of Applied Physiology* **93**, 263-272.
- Hickson, R.C., Kanakis, C., Davis, J.R., Moore, A.M. and Rich, S. (1982) Reduced training duration effects on aerobic power, endurance, and cardiac growth. *Journal of Applied Physiology* **53**, 225-229.
- Hortobágyi, T., Houmard, J.A., Stevenson, J.R., Fraser, D.D. and Johns, R.A., Israel, R.G. (1993) The effects of detraining on power athletes. *Medicine and Science in Sports and Exercise* **25**, 929-935.
- Houmard, J.A., Hortobágyi, T., Johns, R.A., Bruno, N.J., Nute, C.C., Shinebarger, M.H. and Welborn, J.W. (1992) Effect of short-term training cessation on performance measures in distance runners. *International Journal of Sports Medicine* **13**, 572-576.
- Houston, M.E., Bentzen, H. and Larsen, H. (1979) Interrelationships between skeletal muscle adaptations and performance as studied by detraining and retraining. *Acta Physiologica Scandinavica* **105**, 163-170.
- Issurin, V. (2008) *Block periodization. Breakthrough in sport training*. Ultimate Athlete Concepts, Michigan.
- Issurin, V., Kaverin, V. and Nikanorov, A.N. (1986) *Specialized preparation of canoe-kayak paddlers*. State Committee of USSR for Physical Culture and Sport, Moscow.
- Izquierdo, M., Ibañez, J., González-Badillo, J.J., Häkkinen, K., Ratamess, N.A., Kraemer, W.J., French, D.N., Eslava, J., Altadill, A., Asiain X. and Gorostiaga, E.M. (2006) Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. *Journal of Applied Physiology* **100**, 1647-1656.
- Izquierdo, M., Ibañez, J., González-Badillo, J.J., Ratamess, N.A., Kraemer, W.J., Häkkinen, K., Bonnabau, H., Granados, C., French, D.N. and Gorostiaga, E.M. (2007) Detraining and tapering effects on hormonal responses and strength performance. *Journal of Strength and Conditioning Research* **21**, 768-775.
- Kraemer, W.J., Koziris, L.P., Ratamess, N.A., Häkkinen, K., Triplett-McBride, N., Fry, A., Gordon, S., Volek, J., French, D., Rubin, M., Gómez, A., Sharman, M., Lynch, J., Izquierdo, M., Newton, R. and Fleck, S. (2002) Detraining produces minimal changes in physical performance and hormonal variables in recreationally strength-trained men. *Journal of Strength and Conditioning Research* **16**, 373-382.
- Kraemer, W.J. and Ratamess, N.A. (2005) Hormonal responses and adaptations to resistance exercise and training. *Sports Medicine* **35**, 339-361.
- Larsson, L. and Ansved, T. (1985) Effects of long-term physical training and detraining on enzyme histochemical and functional skeletal muscle characteristics in man. *Muscle and Nerve* **8**, 714-722.
- Madsen, K., Pedersen, P.K., Djurhuus, M.S. and Klitgaard, N.A. (1993) Effects of detraining on endurance capacity and metabolic changes during prolonged exhaustive exercise. *Journal of Applied Physiology* **75**, 1444-1451.
- Marles, A., Legrand, R., Blondel, N., Mucci, P., Betbeder, D. and Prieur, F. (2007) Effect of high-intensity interval training and detraining on extra VO_2 and on the VO_2 slow component. *European Journal of Applied Physiology* **99**, 633-640.
- Martin, W.H., Coyle, E.F., Bloomfield, S.A. and Ehsani, A.A. (1986) Effects of physical deconditioning after intense endurance training on left ventricular dimensions and stroke volume. *Journal of the American College of Cardiology* **7**, 982-989.
- Moore, R.L., Thacker, E.M., Kelley, G.A., Musch, T.I., Sinoway, L.I., Foster, V.L. and Dickinson, A.L. (1987) Effect of training/detraining on submaximal exercise responses in humans. *Journal of Applied Physiology* **63**, 1719-1724.
- Mujika, I. and Padilla, S. (2000a) Detraining: loss of training-induced physiological and performance adaptations. Part I. *Sports Medicine* **30**, 79-87.
- Mujika, I. and Padilla, S. (2000b) Detraining: loss of training-induced physiological and performance adaptations. Part II. *Sports Medicine* **30**, 145-154.
- Mujika, I., Padilla, S. (2001) Cardiorespiratory and metabolic characteristics of detraining in humans. *Medicine and Science in Sports and Exercise* **33**, 413-421.
- Neufer PD. (1989) The effect of detraining and reduced training on the physiological adaptations to aerobic exercise training. *Sports Medicine* **8**, 302-320.
- Neufer, P.D., Costill, D.L., Fielding, R.A., Flynn, M.G. and Kirwan, J.P. (1987) Effect of reduced training on muscular strength and endurance in competitive swimmers. *Medicine and Science in Sports and Exercise* **19**, 486-490.
- Petitobis, C. and Déléris, G. (2003) Effects of short- and long-term detraining on the metabolic response to endurance exercise. *International Journal of Sports Medicine* **24**, 320-325.

Key points

- Short-term (5-wk) training cessation in top-level athletes results in larger declines in physiological and performance parameters when compared to a reduced training approach.
- Following a competitive season in top-level athletes, both TC and RT strategies reflect an increased androgenic-anabolic activity. A higher T:C ratio was observed for the RT compared to the TC group.
- These results suggest the convenience of maintaining some reduced training program during transition periods in an attempt to minimize decreases in endurance performance between seasons.

AUTHORS BIOGRAPHY

**Jesús GARCÍA-PALLARÉS****Employment**

PhD student at Faculty of Sport Sciences, University of Murcia, Murcia, Spain.

Degree

MSc, PhD candidate

Research interests

Exercise physiology and training; performance analysis; kayaking/canoeing.

E-mail: jesus.garcia.pallares@gmail.com

**Luis CARRASCO****Employment**

Professor at Department of Physical Education and Sport, Faculty of Education Sciences, University of Seville, Seville, Spain.

Degree

MSc, PhD

Research interests

Exercise physiology; exercise testing; stress hormone response.

E-mail: lcarrasco@us.es

**Arturo DÍAZ****Employment**

Professor at Faculty of Sport Sciences, University of Murcia, Murcia, Spain.

Degree

PhD

Research interests

Sports training; physical activity for health improvement; sports management.

E-mail: ardiaz@um.es

**Luis SÁNCHEZ-MEDINA****Employment**

Professor at Faculty of Sport, Pablo de Olavide University, Seville, Spain.

Degree

MSc, PhD candidate

Research interests

Exercise testing; strength training and conditioning; interactions between concurrent resistance and endurance training; technology for sports performance monitoring.

E-mail: lsmolina@upo.es

✉ **Jesús García-Pallarés**

Faculty of Sport Sciences, University of Murcia, Spain