UNIVERSIDAD DE MURCIA

Departamento de Fisiología

PERIODIZACIÓN DEL ENTRENAMIENTO DE FUERZA Y RESISTENCIA EN PIRAGÜISTAS DE ALTO NIVEL

JESÚS GARCÍA PALLARÉS

Tesis Doctoral

DICIEMBRE DE 2009

UNIVERSIDAD DE MURCIA
ÁREA DE GESTIÓN ACADÉMICA
SECCIÓN DE POSTGRADO
Fecha: 23-11-2009
SALIDA Nº 740

UNIVERSIDAD DE
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D. JESÚS GARCÍA PALLARÉS

Vista la solicitud presentada por D. JESÚS GARCÍA PALLARÉS, con DNI número 77705726, sobre autorización para presentación de tesis doctoral como compendio de publicaciones con carácter previo a la tramitación de la misma en la Universidad de Murcia, le comunico que la Comisión de General de Doctorado, vistos:

- El informe previo del Departamento de Fisiología, responsable de la autorización de la tesis doctoral en fase de elaboración, de esta Universidad, y
- El visto bueno de la Comisión de Ramas de Conocimiento de Ciencias de la Salud,

resolvió, en su sesión de 20 de noviembre de 2009, **ACCEDER** a lo solicitado por el interesado pudiendo, por lo tanto, presentar su tesis doctoral en la modalidad de compendio de publicaciones.

Lo que en cumplimiento del artículo 58 de la vigente Ley 30/1992, de Régimen Jurídico de las Administraciones Públicas y del Procedimiento Administrativo Común, de 26 de noviembre, se **notifica a** D. JESÚS GARCÍA PALLARÉS, significándole que contra esta resolución, que pone fin a la vía administrativa, se podrá interponer potestativamente ante el mismo órgano que la ha dictado, recurso de reposición, en el plazo de un mes a contar desde el día siguiente a su notificación, de acuerdo con lo dispuesto en el art. 116 de la citada Ley.

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Murcia, 23 de noviembre de 2009
Vicerrectora de Estudios y
Presidenta de la Comisión General de Doctorado

Concepción Palacios Bernal

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Vicerrectorado de Estudios

La tesis que aquí se presenta es un compendio de las tres publicaciones más relevantes del doctorando:

- 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

- García-Pallarés J, Carrasco L, Díaz A, Sánchez-Medina L (2009) Post-season detraining effects on physiological and performance parameters in top-level kayakers: comparison of two recovery strategies. J Sports Sci and Med. In Press

- García-Pallarés J, Sánchez-Medina L, Pérez CE, Izquierdo-Gabarren M, Izquierdo M (2010) Physiological effects of tapering and detraining in world-class kayakers. Med Sci Sports Exerc. In Press

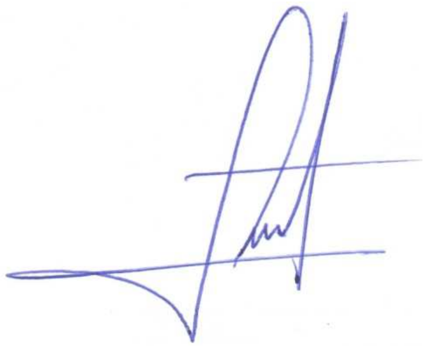
Con ánimo de conseguir una apariencia homogénea, las tres publicaciones se presentan en el mismo formato en la versión original en inglés así como su traducción al castellano. En el apartado de anexos se han incluido las publicaciones tal y como fueron editadas en la revista.

D. Mikel Izquierdo Redín, Jefe de la Unidad Técnica de Investigación del Centro de Estudios, Investigación y Medicina del Deporte del Gobierno de Navarra, AUTORIZA:

La presentación de la Tesis Doctoral titulada “P*eriodización del entrenamiento de fuerza y resistencia en piragüistas de alto nivel*”, realizada por D. Jesús García Pallarés, bajo mi inmediata dirección y supervisión, y que presenta en la modalidad de *compendio de publicaciones* para la obtención del grado de Doctor por la Universidad de Murcia.

En Murcia, a 23 de noviembre de 2009.

Fdo. Mikel Izquierdo Redín



D. Arturo Díaz Suárez, Profesor Titular del Departamento de Actividad Física y Deporte de la Universidad de Murcia, AUTORIZA:

La presentación de la Tesis Doctoral titulada “P*eriodización del entrenamiento de fuerza y resistencia en piragüistas de alto nivel”*, realizada por D. Jesús García Pallarés, bajo mi inmediata dirección y supervisión, y que presenta en la modalidad de *compendio de publicaciones* para la obtención del grado de Doctor por la Universidad de Murcia.

En Murcia, a 23 de noviembre de 2009.

Fdo. Arturo Díaz Suárez

A mis Padres, gracias por todo a lo que habéis renunciado por mí

Espero poder llegar a merecer algún día tanto esfuerzo, sacrificio y dedicación

AGRADECIMIENTOS

El resultado deportivo suele ser lo único que queda en el recuerdo de la mayoría, pero para los que hemos estado involucrados en este proyecto, este documento creo que refleja la relevancia del proceso, la importancia del trabajo en equipo, los grandes sacrificios que requiere el deporte de alto nivel, y lo más importante, la necesidad de crecerse ante la adversidad.

Muchas son las personas que han hecho posible alcanzar los éxitos deportivos de este equipo, y muchas otras han colaborado enérgicamente para dejar documentada esta experiencia; por ello quisiera citarlos a todos, ya que todos han sido imprescindibles.

Miguel García es sin duda el principal artífice de los triunfos de este grupo humano. No se puede describir en estas líneas la inmensa calidad de su trabajo, la completa dedicación que ha tenido al proyecto y la fuerza de superación que demostró en las situaciones más adversas. No creo que el Piragüismo español pueda nunca reconocer como se merece el enorme sacrificio que él y su familia han hecho por este deporte.

Igualmente es necesario reconocer la labor indispensable de otros excepcionales profesionales que pelearon día a día por nuestra meta común como Ignacio López Moranchel, Rodrigo Tiebo, Raquel Ortelano y José Seguín.

Así mismo, destacar la labor y la dedicación de mis dos directores de tesis Mikel Izquierdo y Arturo Díaz, así como la de mis amigos y estrechos colaboradores Luis Carrasco Páez, Luis Sánchez Medina y Carlos Pérez Caballero. Todos ellos han hecho posible publicar estos documentos y difundir como creo que se merece esta experiencia.

Agradecer al Departamento de Fisiología de la Universidad de Murcia, así como al tutor de esta tesis y decano de la Facultad de Medicina Dr. Joaquín García-Estañ López su inestimable apoyo en la elaboración de esta tesis por compendio.

Finalmente hacer una mención especial a todos los palistas que han integrado este equipo en los últimos cuatro años, ya que ellos han sido los verdaderos artistas:

Jaime Acuña, Pablo Baños, Omar Calzón, Miguel F. Castañón, Diego Cosgaya, Jovino G. Comesaña, Saúl Craviotto, Álvaro F. Fiuza, Javier Hernanz, Emilio Llamedo, Francisco Llera, Álvaro M. Pacheco, Manuel Muñoz, Julio Moreno, Carlos Pérez Rial, Borja Prieto, Ekaitz Saies y Damián Vindel.

ÍNDICE

ABREVIATURAS

$[La^-]_{pico}$:	Concentración de ácido láctico pico tras concluir el test incremental máximo en kayak ergómetro
1RM:	Una repetición máxima
CE:	Parada del entrenamiento
DR:	Dorsal en remo
DTR:	Desentrenamiento
F1:	1ª fase del ciclo de 12 semanas de entrenamiento periodizado
F2:	2ª fase del ciclo de 12 semanas de entrenamiento periodizado
F3:	3ª fase del ciclo de 12 semanas de entrenamiento periodizado
FC:	Frecuencia cardiaca
FC_{max}:	Frecuencia cardiaca en el consumo máximo de oxígeno
FC_{VT2}:	Frecuencia cardiaca en el segundo umbral ventilatorio
FP:	Frecuencia de paleo
FP_{max}:	Frecuencia de paleo en el consumo máximo de oxígeno
FP_{VT2}:	Frecuencia de paleo en el segundo umbral ventilatorio
ISAK:	International Society for the Advancement of Kineanthropometry
PB:	Ejercicio de pectoral en banca
Pw:	Potencia mecánica
Pw_{max}:	Potencia mecánica en el consumo máximo de oxígeno
Pw_{VT2}:	Potencia mecánica en el segundo umbral ventilatorio
RE:	Reducción de entrenamiento
Sum:	Sumatorio
T0-T6:	Enumeración de cada uno de las baterías de test llevados a cabo durante el estudio

TAP:	Fase de puesta a punto o afinamiento.
$V_{45\%}$	Velocidad media de la fase concéntrica con el 45% del 1RM
V_{max}:	Velocidad aeróbica máxima
VO_{2max}:	Consumo máximo de oxígeno
VO_2VT2:	Consumo de oxígeno en el segundo umbral ventilatorio
VT2:	Segundo umbral ventilatorio
VT2(%VO_{2max}):	Porcentaje de consumo de oxígeno en el segundo umbral ventilatorio
V_{VT2}:	Velocidad de desplazamiento en el segundo umbral ventilatorio
Z1:	Zona de entrenamiento de la resistencia de baja intensidad, por debajo del VT2.
Z2:	Zona de entrenamiento de la resistencia de media intensidad, entre VT2 y el 90% del VO_{2max}.
Z3:	Zona de entrenamiento de la resistencia de alta intensidad, por encima del VO_{2max}.

1

JUSTIFICACIÓN DEL ESTUDIO

1. JUSTIFICACIÓN DEL ESTUDIO

Numerosas investigaciones se han centrado en las últimas cuatro décadas en incrementar el conocimiento sobre todos los procesos biológicos que tienen lugar de forma aislada en la práctica deportiva de alto nivel. No obstante, muy pocas investigaciones llevadas a cabo con el rigor científico adecuado han estudiado los efectos que la interconexión de los diferentes estímulos de entrenamiento, su periodización y su organización tienen sobre el rendimiento físico de deportistas de élite.

Concretamente, en la especialidad del piragüismo, diferentes líneas de trabajo han centrado sus esfuerzos en el estudio descriptivo y trasversal en palistas de medio y alto nivel, aportando de esta forma conocimiento científico de base, pero realmente con poca aplicabilidad para los técnicos responsables de los diferentes equipos y clubes. Muy pocos investigadores han podido tener acceso a piragüistas de élite para realizar estudios longitudinales, conocer la respuesta del organismo y la evolución del rendimiento de forma descriptiva, pero también con intervención y manipulación de los procesos de entrenamiento.

Una tesis por compendio, no sólo es válida para alcanzar el grado de doctor, sino que simultáneamente, la publicación de estos artículos en revistas de reconocido prestigio y especializadas en la fisiología del esfuerzo, garantizan una adecuada difusión de los resultados y conclusiones más importantes de esta investigación.

2

RESUMEN

2.- RESUMEN

2.1.- Antecedentes

La manipulación de las variables que definen el programa de entrenamiento (intensidad, orientación, frecuencia y volumen de entrenamiento), con objeto de maximizar las adaptaciones fisiológicas del deportista es una estrategia comúnmente aceptada por los entrenadores y científicos del deporte. Esta periodización del entrenamiento se hace especialmente importante en aquellos deportes donde es necesario el desarrollo simultáneo de fuerza y resistencia para optimizar el rendimiento deportivo. Debido a que el entrenamiento de fuerza y resistencia produce distintos, e incluso a menudo opuestos, mecanismos adaptativos (Nader 2006; Sale y cols. 1990), el desarrollo combinado de ambos componentes en el mismo régimen de entrenamiento puede desencadenar en un conflicto de adaptaciones neuromusculares. Este fenómeno de interferencia fue descrito en un primer momento por Hickson (1980), quién observó conflictos en las adaptaciones de la fuerza cuando la resistencia y la fuerza se desarrollaban de forma combinada. Sin embargo, los resultados de investigaciones posteriores han sido dispares, con estudios cuyos resultados concuerdan con las aportaciones de Hickson (Bell y cols. 2000; Craig y cols. 1991; Dudley y Djamil 1985; Hennessy y Watson 1994; Kraemer y cols. 1995) y otros que los cuestionan (Häkkinen y cols. 2003; Hunter y cols. 1987; McCarthy y cols. 1995, 2002; Sale y cols. 1990). Otras investigaciones han propuesto diferentes mecanismos y estrategias de entrenamiento que parecen minimizar los conflictos en las adaptaciones de fuerza y resistencia cuando ambas capacidades se desarrollan simultáneamente, como son la periodización del entrenamiento (Fleck 1999; Willoughby 1993) y el control de la frecuencia de entrenamiento (Hunter y cols. 1987; Kraemer y cols. 1995).

Igualmente, llevar a cabo una fase de puesta a punto para optimizar el rendimiento de los deportistas antes de los objetivos prioritarios de competición es una estrategia generalmente aceptada por entrenadores e investigadores. Esta fase se caracteriza por una marcada reducción del volumen de entrenamiento mientras que la intensidad se mantiene elevada (Gibala y cols. 1994; Izquierdo y cols. 2007; Mujika y Padilla 2000a; Mujika y Padilla 2003; Mujika y cols. 2004). La mayoría de estas investigaciones han relacionado los aumentos del rendimiento de los deportistas con una mejora de los procesos de recuperación durante estas fases (Gibala y cols. 1994; Mujika y Padilla 2003; Mujika y col. 2004).

Una vez concluidas estas fases de optimización del rendimiento, la periodización del entrenamiento en el deporte de alto nivel hace hincapié en la necesidad de incorporar en el programa periodos de regeneración tras la conclusión de los eventos principales de la temporada. El objetivo de estas fases es permitir una completa recuperación física y mental del deportista antes de comenzar un nuevo ciclo de entrenamiento. Históricamente la cesión completa de entrenamiento ha sido la estrategia escogida por los entrenadores para llevar a cabo esos periodos de transición entre temporadas. No obstante, numerosas investigaciones han registrado graves descensos del rendimiento en deportistas bien entrenados tras estos periodos de ausencia de estímulos de entrenamiento (Häkkinen y cols. 1981; Häkkinen y cols. 1985; Hortobágyi y cols. 1993; Houmard y cols. 1993; Izquierdo y cols. 2007; Mujika y Padilla 2001). Con ánimo de reducir los efectos negativos que la ausencia de estímulos de entrenamiento parecen tener sobre el rendmiento deportivo, se han propuesto estrategias de reducción de entrenamiento; periodos durante los cuales el volumen y/o la intensidad se reducen significativamente, como alternativa a la cesión completa del entrenamiento especialmente en deportistas de alto nivel (Mujika y Padilla 2000a, 2000b; Neufer 1989; Neufer y cols. 1987). No obstante, existe escasez de información sobre los efectos que tienen estas fases de cesión y reducción de entrenamiento sobre los parámetros fisiológicos y de rendimiento deportivo en deportistas de alto nivel.

Por todo ello, esta investigación se llevó a cabo para analizar los cambios en las variables cardiorrespiratorias, neuromusculares, hormonales, de composición corporal y específicas de rendimiento de un grupo de kayakistas de élite mundial, durante una temporada completa de entrenamiento periodizado. Se estudiaron las adaptaciones producidas por el entrenamiento concurrente de fuerza y resistencia, los efectos que las fases de puesta a punto tienen sobre el éxito en competición, así como y los consecuencias que las estrategias de cesión total o reducción parcial del entrenamiento producen en el rendimiento de estos deportistas de alto nivel.

2.2.- Hipótesis

- El entrenamiento concurrente de fuerza y resistencia en deportistas de alto nivel produce conflictos en las adaptaciones de ambas capacidades.

- Las fases de puesta a punto permiten a los deportistas de alto nivel aumentar el rendimiento de las capacidades físicas relacionadas con el éxito en competición.

- Durante las fases de transición entre temporadas, la cesión total de entrenamiento produce importantes descensos del rendimiento físico en deportistas de alto nivel.

- La estrategia de reducción de entrenamiento permite amortiguar parte de los descensos del rendimiento que se producen con la cesión total de entrenamiento durante las fases de transición entre temporadas.

2.3.- Objetivos

Objetivo general

Estudiar la evolución de los diferentes parámetros condicionantes del rendimiento en piragüistas de élite durante una temporada completa de entrenamiento periodizado.

Objetivos específicos

- Determinar la evolución del consumo máximo de oxígeno (VO_{2max}), Umbral Ventilatorio 2 (VT2), porcentaje del consumo de oxígeno en VT2 respecto al VO_{2max} ($VT2(\%VO_{2max})$), frecuencia cardiaca en VO_{2max} (FC_{max}) y en VT2 (FC_{VT2}), como principales parámetros cardiorrespiratorios determinantes del rendimiento en piragüistas de alto nivel a lo largo de las diferentes fases de entrenamiento, competición y recuperación.

- Establecer, tras las diferentes fases de entrenamiento, puesta a punto y desentrenamiento, el grado de variación experimentado por los parámetros técnicos y de rendimiento específicos en piragüismo, como son la velocidad aeróbica máxima (V_{max}), la velocidad correspondiente al VT2 (V_{VT2}), la frecuencia de paleo en VO_{2max} (FP_{max}) y en VT2 (FP_{VT2}), así como la potencia mecánica de paleo en VO_{2max} (Pw_{max}) y en VT2 (Pw_{VT2}).

- Analizar la incidencia de las diferentes fases de entrenamiento sobre la fuerza dinámica máxima y la potencia mecánica en los ejercicios de entrenamiento de fuerza más específicos para el piragüista.

- Determinar el volumen, intensidad, orientación y acumulación de carga requeridos para la mejora de las variables cardiorrespiratorias (VO_{2max} y VT2) y neuromusculares (fuerza dinámica máxima y potencia) condicionantes del éxito en competición en palistas de élite mundial.

- Detectar las interferencias que se generan el entrenamiento concurrente de fuerza y resistencia en piragüistas de alto nivel, así como establecer posibles mecanismos de intervención para disminuir estos conflictos en las adaptaciones.

- Definir los efectos que, sobre la composición corporal de piragüistas de alto nivel, y más en concreto, en parámetros como la masa corporal, el sumatorio de pliegues y la masa libre de grasa, conlleva la realización de una temporada completa de entrenamientos, competición y recuperación.

- Conocer las diferencias producidas en el rendimiento de palistas de alto nivel en función de la estrategia de recuperación escogida para el periodo de transición entre temporadas (cesión total o reducción parcial de entrenamiento).

2.4.- Material y Métodos

Muestra

Dieciocho kayakistas varones de alto nivel (incluidos 16 finalistas en Campeonatos del Mundo y dos Campeones Olímpicos) tomaron parte de forma voluntaria en este estudio. Las características de los sujetos fueron (media ± desviación estándar o DE): edad 24.4 ± 2.0 años; talla 1.81 ± 0.05 m; masa corporal 83.5 ± 5.1 kg; experiencia en el entrenamiento 10.3 ± 2.0 años, una repetición máxima (1RM) en press banca 136.8 ± 8.6 kg; 1RM en dorsal remo 130.9 ± 7.0 kg, VO_{2max} 64.8 ± 3.3 $mL \cdot kg^{-1} \cdot min^{-1}$, volumen de paleo anual 4385 ± 369 km. Este estudio, que cumplió con la Declaración de Helsinki, fue aprobado por el Comité de Bioética de la Universidad de Sevilla, y para el cual se obtuvo un consentimiento informado de los deportistas antes de comenzar la investigación.

Diseño general del estudio

Se realizó un seguimiento exhaustivo de la evolución de las diferentes variables que condicionan el éxito en piragüismo de alto nivel durante una temporada completa (43 semanas) de entrenamiento concurrente de fuerza y resistencia, a lo largo de una fase de 4 semanas de puesta a punto (TAP), así como durante una fase de desentrenamiento (DTR) de 5 semanas en la que mitad de los palistas cesaron totalmente los estímulos de entrenamiento (CE) y la otra mitad realizaron únicamente una sesión de entrenamiento de fuerza y dos de resistencia semanales (RE).

A lo largo de esas 53 semanas los palistas repitieron periódicamente una batería de test, distribuidos de forma estratégica en el programa de entrenamiento (Figura 1), que permitió conocer la evolución de los parámetros condicionantes del rendimiento (variables independientes). Igualmente se registró en todo momento la cuantificación de todos los estímulos de entrenamiento (variable dependiente), diferenciando volumen, intensidad y orientación de cada estímulo propuesto de forma individual a cada sujeto experimental.

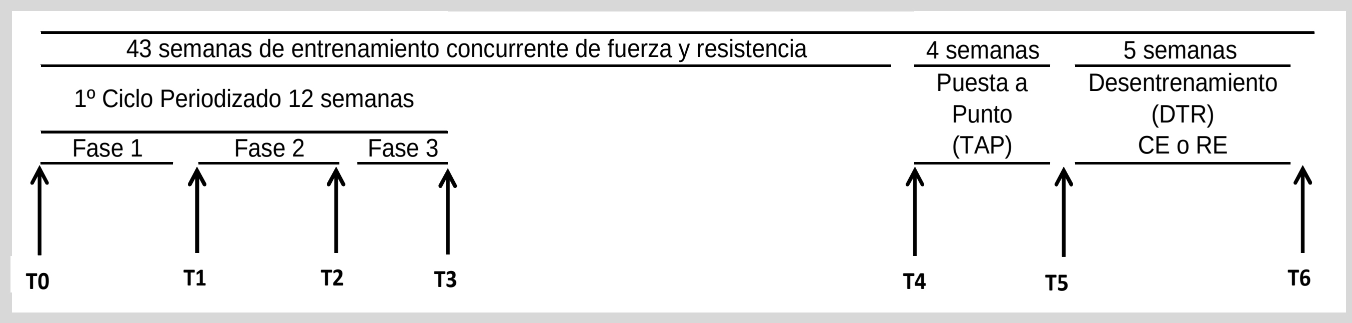


Figura 1. Diseño general del estudio.

Programa de entrenamiento

Desde la semana 1 hasta la semana 43 los palistas tomaron parte en un programa de entrenamiento concurrente de fuerza y resistencia, bajo la supervisión de entrenadores profesionales con varios años de experiencia en el entrenamiento de piragüistas. El entrenamiento de fuerza se estructuró en cuatro ciclos periodizados de 10-12 semanas, durante los cuales se completaron secuencialmente tres fases diferentes de entrenamiento de fuerza: hipertrofia (8-10 repeticiones, 4-5 series, 70-75% del 1RM, 2 minutos de recuperación entre series); fuerza máxima (3-4 repeticiones, 3-4 series, 85-90% del 1RM, 4 minutos de recuperación entre series); y potencia máxima (5-8 repeticiones, 4-5 series, 45-60% del 1RM, 4 minutos de recuperación entre series). Se emplearon 5 ejercicios principales: press banca (PB), dorsal remo (DR), press de hombros, dominadas y sentadilla. Se evitó alcanzar la repetición del fallo en todas las series de entrenamiento de hipertrofia y fuerza máxima, y se motivó constantemente a los palistas para que realizasen la fase concéntrica de cada repetición a la máxima velocidad voluntaria. En las sesiones de entrenamiento de potencia máxima, cada serie se dio por concluida cuando la velocidad media descendía por debajo del 10% de la mejor repetición (la repetición con la fase concéntrica más rápida). El volumen total de entrenamiento durante las primeras 43 semanas ascendió a: 37.8 ± 2.6 h, 42 ± 3 sesiones, 840 ± 60 series y 7,560 ± 540 repeticiones de entrenamiento de hipertrofia; 41.8 ± 3.3 h, 38 ± 3 sesiones, 608 ± 48 series y 2,492 ± 197 repeticiones de entrenamiento de fuerza máxima; y 30.0 ± 1.1 h, 30 ± 2 sesiones, 450 ± 30 series y 2,475 ± 165 repeticiones de entrenamiento de máxima potencia. El entrenamiento de resistencia se estructuró en 3 ciclos de 11-22 semanas de duración. El volumen total de entrenamiento de resistencia que realizaron los palistas ascendió a 249.2± 13.2 h de paleo a la velocidad correspondiente al 75-90% del VO_{2max}, 35.7 ± 2.2 h entre el 90-105% del VO_{2max}, y 7.1 ± 0.6 h por encima del 105% VO_{2max}. Los atletas completaron entre 60-130 km (10-15 sesiones) a la semana.

La fase de TAP consistió en 4 semanas caracterizadas por un aumento de la intensidad de entrenamiento y un descenso progresivo del volumen. Durante esta fase los palistas completaron dos sesiones de entrenamiento de fuerza semanales: a) una sesión de fuerza máxima 90-95% 1RM (3-4RM), 2-4 repeticiones por serie, y 2-3 series por ejercicio; b) una sesión de potencia máxima con el 45% (PB, DR) o el 60% 1RM (sentadilla), 5-8 repeticiones y 3-4 series. Durante esta fase de TAP, los palistas realizaron únicamente los ejercicios de PB, DR y sentadilla. El tiempo total de entrenamiento de fuerza fue 2.6 ± 0.3 h, 34 ± 2 series y 108 ± 4 repeticiones de fuerza máxima; y 2.4 ± 0.2 h, 38 ± 5 series y 198 ± 34 repeticiones de potencia máxima. Además, los palistas completaron 5-10 sesiones de paleo semanales, durante las cuales se priorizó el entrenamiento de alta intensidad, mientras el volumen de entrenamiento se reducía progresivamente hasta un 50% del volumen habitual de entrenamiento. El volumen total de entrenamiento durante la fase de TAP ascendió a 14.3 ± 0.6 h de paleo a la velocidad correspondiente al 75-90% VO_{2max}, 4.2 ± 0.1 h entre el 90-105% VO_{2max} y 1.5 ± 0.3 horas por encima 105% VO_{2max}. Además los palistas realizaron tres días de competición al final de esta fase.

Finalmente, durante la fase de DTR, el grupo de CE detuvo completamente cualquier tipo de entrenamiento físico durante las siguientes 5 semanas, mientras que el grupo de RE realizó únicamente una sesión de entrenamiento de fuerza y dos sesiones de entrenamiento de resistencia a la semana. Durante este periodo no hubo control sobre la dieta de los deportistas. Las sesiones de entrenamiento de fuerza llevadas a cabo por el grupo de RE estaban compuestas por 3 series de 10 repeticiones con el 70-75% del 1RM de cada palista (10-12RM) en los ejercicios de PB, DR y sentadilla, respetando 3-min de recuperación entre series. El volumen de entrenamiento de resistencia consistió en 40 minutos de paleo y carrera a intensidad moderada (~80% VO_{2max}). En los cuatro días restantes no se realizó ningún tipo de entrenamiento físico.

Programa de valoraciones

Cada batería de test estuvo compuesta por un conjunto de valoraciones de la condición física, que permitieron conocer la evolución del proceso de entrenamiento de forma individual. Los test más representativos fueron:

Test incremental maximal en kayak ergómetro

Tras 5 minutos de calentamiento a una velocidad de 9 $km \cdot h^{-1}$, los sujetos completaron un test incremental de paleo hasta el agotamiento en un kayak-ergómetro (Dansprint ApS, Denmark). El primer escalón del test se completó a 11.5 $km \cdot h^{-1}$, y la velocidad se incrementó 0.5 $km \cdot h^{-1}$ cada minuto**.** Cada sujeto adaptó libremente la frecuencia de paleo a sus necesidades. Se alentó a los palistas a realizar el máximo esfuerzo voluntario y completar el mayor número posible de escalones del test. Se realizó un análisis de gases respiración a respiración empleando para ello un analizador de gases Jaeger Oxycon Pro system (Erich Jaeger, Germany). Una vez concluido el test se establecieron las principales variables cardiorrespiratorias (VO_{2max}, VO_2 en VT2, VT2(%VO_{2max}), FC_{max}, FC_{VT2}), metabólicas ($[La^-]_{pico}$) así como las principales variables relacionadas con el rendimiento en piragüismo (V_{max}, V_{VT2}, Pw_{max} y Pw_{VT2}, así como la FP_{max} y FP_{VT2}).

Composición corporal

Las medidas antropométricas practicadas fueron: talla, masa corporal, pliegues cutáneos (tríceps, subescapular, suprailiaco, abdominal, muslo anterior, pierna medial, supraespinal y bíceps braquial). Todas ellas fueron tomadas por el mismo investigador experimentado, de acuerdo con las directrices de la International Society for the Advancement of Kineanthropometry (ISAK). El porcentaje graso y la masa libre de grasa se estimaron empleando la fórmula de Carter y Yuhasz de 1984.

Valoración de la fuerza dinámica máxima y la velocidad ante cargas de máxima potencia

Se determinó el valor de una repetición máxima (1RM) en los ejercicios de press banca y dorsal remo en peso libre. Estos ejercicios fueron elegidos ya que son los más empleados en los entrenamientos de fuerza de piragüistas, a la vez que son útiles para valorar la fuerza y potencia de acciones musculares opuestas del tren superior (empuje y tracción). La carga más pesada que cada sujeto pudo levantar, sin ningún tipo de ayuda externa, fue considerada su 1RM. El día siguiente se evaluó en ambos ejercicios la velocidad media de la fase concéntrica con el 45% del 1RM ($V_{45\%}$) establecido previamente. Esta carga fue escogida deliberadamente ya que coincide con la resistencia que maximiza la potencia mecánica media para ejercicios del tren superior. Lo palistas realizaron 2 series de 3 repeticiones con el 45% del 1RM, respetando 5 minutos de pausa entre series. La velocidad media de la fase concéntrica fue medida por un trasductor lineal de posición (MuscleLab, Ergotest Technology, Oslo, Norway). La $V_{45\%}$ se definió como la velocidad media de las tres mejores repeticiones de cada sujeto.

Análisis de sangre

Se tomaron muestras de sangre venosa (10 mL) de la vena antecubital empleando para ello vacutainers y agujas estériles. Todas las muestras fueron obtenidas a la misma hora del día en todos los sujetos (8-9 h) tras 12 horas de ayuno nocturno y un día completo de recuperación previo. La muestras de sangre se recogieron en tubos con EDTA, centrifugadas a 800 g durante 10 min a 4ºC, y el plasma se almacenó a -80ºC hasta que se analizaron por duplicado la testosterona total (T) y el cortisol (C) por radioinmunoanálisis (125I RIA kits, DiaSorin, MN, USA).

2.5.- Resultados

Cambios en las variables cardiorrespiratorias y específicas del rendimiento

El VO_{2max} aumentó significativamente ($P < 0.05$) un 9.5% y un 10.5% durante las primeras 12 y 43 semanas de entrenamiento periodizado respectivamente. Tras la fase DTR, se observaron descensos significativamente mayores para el grupo de CE (-11.3%, de 69.1 a 61.3 $mL \cdot kg^{-1} \cdot min^{-1}$, $P < 0.05$) comparado con el grupo de RE (-5.6%, de 68.5 a 64.6 $mL \cdot kg^{-1} \cdot min^{-1}$, n.s.). Por su parte los niveles de VO_2VT2 se incrementaron significativamente ($P < 0.05$) un 8.4% y un 11.5% durante las primeras 12 y 43 semanas de entrenamiento periodizado respectivamente. Tras la fase de DTR el VO_2VT2 descendió en el grupo de CE (-8,8%, $P < 0.01$) y en el de RE (-5.7%, $P < 0.05$). La FC_{VT2} aumentó en el grupo de CE durante la fase de DTR (3.5%, $P < 0.05$), alcanzando valores significativamente mayores ($P < 0.05$) de esta variable que el grupo RE al final del periodo de desentrenamiento. No se obervaron cambios significativos en el FC_{max}, ni en $[La^-]_{pico}$ a lo largo del estudio.

La V_{max} aumentó significativamente durante las primeras 12 y 43 semanas de entrenamiento un 6.2% y un 8.4% respectivamente. Por su parte, la V_{VT2} aumentó un 4.0% durante las primeras 12 semanas, hasta alcanzar un aumento de 6.1% al finalizar las 43 semanas de entrenamiento periodizado. Durante la fase de DTR, la V_{VT2} descenció tanto en el grupo de CE (-5.0%) como en el de RE (-4.2%) ($P < 0.05$), mientras que la V_{max} descendió de forma significativa únicamente en el grupo de CE (-3.3%, $P < 0.05$). La frecuencia de paleo en VO_{2max} y VT2 se mostró estable durante las 43 semanas del programa de entrenamiento, aunque experimentó incrementos significativos en el grupo de CE (5.2% y 4.9%, $P < 0.05$, respectivamente) durante la fase de DTR. Tras las 5 semanas de desentreamiento, la Pw_{max} descendió significativamente en ambos grupos (-7.9% y -3.9%, $P < 0.05$, en los grupos de CE y RE respectivamente), registrando valores significativamente superiores en el grupo de RE al finalizar esta fase DTR. La magnitud de los descensos en la Pw_{VT2} (-11%, $P < 0.05$) fue idéntica en ambos grupos durante la fase de DTR.

Cambios de fuerza y potencia

Durante el primer ciclo de entrenamiento de 12 semanas los valores de 1RM experimentaron aumentos de un 4.8 y 5.5% en PB y DR respectivamente. Por su parte la $V_{45\%}$ registró aumentos de mayor magnitud, alcanzando incrementos del 14,4% y 10% en PB y DR respectivamente durante este mismo periodo de tiempo. Hacia el final de las primeras 43 semanas de entrenamiento periodizado se detectaron aumentos significativos ($P < 0.05$) en el 1RM (8.5% y 11.0%) y en la $V_{45\%}$ (13.7% y 9%) en los ejercicios de PB y DR respectivamente. No hubo cambios en ninguna de las dos variables neuromusculares estudiadas (1RM y $V_{45\%}$) durante la fase de puesta a punto (TAP). Tras la fase de DTR, se observaron descensos significativamente mayores en el 1RM del grupo de CE (-8.9% y -7.8%, $P < 0.05$, para el PB y DR respectivamente) que el grupo de RE (-3.9% y -3.4%, n.s.). Los descensos en el $V_{45\%}$ en los ejercicios de PB y DR fueron mayores en el grupo de CE (-12.6% y -10.0%, respectivamente) que los observados par el grupo de RE (-9.0% y -6.7%). No se detectaron diferencias significativas entre grupos (CE y RE) en la magnitud de los cambios en la $V_{45\%}$.

Composición corporal

No se observaron cambios en el sumatorio de 8 pliegues tras el primer ciclo de entrenamiento de 12 semanas, aunque el sumatorio de 8 pliegues experimentó una caída del -18.4% tras las 43 semanas de entrenamiento periodizado. Al finalizar la fase de TAP se detectaron descensos no significativos en el sumatorio de 8 pliegues en el grupo de CE (-4.9%) y de RE (-5.3%). Finalmente, durante la fase de DTR se detectaron incrementos significativos ($P < 0.05$) en el sumatorio de 8 pliegues para el grupo de CE (22.8%) y de RE (23.2%). Durante la fase de DTR, la masa libre de grasa registró descensos significativamente mayores para el grupo de CE (-3%, $P < 0.05$) comparado con el de RT (-0.1%, n.s). La masa corporal no mostró cambios significativos en ningún momento de la investigación.

Concentración hormonal basal

Durante la fase de DTR se detectaron descensos similares (-30%, $P < 0.01$) en los niveles de cortisol en ambos grupos (CE y RE). Los niveles de testosterona incremenaron de forma similar en los dos grupos (CE y RE), aunque no fueron cambios significativos. El ratio T:C aumentó ($P < 0.01$) en el grupo de CE (62.5%) y en el de RE (67.6%), hallándose valores significativamente mayores en el grupo de RE que el grupo de CE al finalizar la fase de desentrenamiento ($P < 0.05$).

2.6.- Conclusiones

Los principales hallazgos de esta investigación pueden resumirse de forma esquemática en:

- Un ciclo de 12 semanas de entrenamiento periodizado fue efectivo para producir adaptaciones positivas tanto en las variables de fuerza como en las de resistencia, mostrando que es posible llevar a cabo un desarrollo simultáneo de estas capacidades en relativamente cortos periodos de tiempo y en sujetos altamente entrenados. Las principales decisiones estratégicas aplicadas al programa de entrenamiento concurrente que parecen haber tenido incidencia positiva en el rendimiento de los deportistas fueron:

- Priorizar el desarrollo de unos componentes específicos del rendimiento físico en fases independientes (hipertrofia muscular y VT2 en Fase A; fuerza máxima y potencia aeróbica en Fase B). Esta secuenciación selectiva parece optimizar la efectividad del programa y maximizar las mejoras de rendimiento en las variables cardiorrespiratorias y neuromusculares.

- Evitar deliberadamente la combinación del entrenamiento de hipertrofia muscular y el de potencia aeróbica, ya que se ha comprobado que ambos métodos de entrenamiento producen prioritariamente adaptaciones fisiológicas opuestas a nivel periférico, e impiden al organismo un desarrollo óptimo y simultáneo de ambos componentes del rendimiento.

- Evitar alcanzar la repetición del fallo en cada serie de entrenamiento y focalizar la atención para realizar cada repetición a la máxima velocidad concéntrica posible. Ambas estrategias permitirán maximizar las adaptaciones en el componente neural de la fuerza, así como evitar inducir excesiva fatiga o estrés metabólico y mecánico en el deportista que pudiera tener una influencia negativa en la calidad de las sesiones posteriores de entrenamiento.

- Detener el número de repeticiones por serie en el entrenamiento de potencia cuando la velocidad media de la repetición descienda un 10% de la velocidad registrada para la repetición más rápida en cada serie. Esto garantiza alcanzar altos valores de potencia en unas pocas repeticiones por serie, así como facilitar que cada una de ellas se realice en ausencia o con mínima fatiga neuromuscular.

- Limitar la frecuencia de entrenamiento de fuerza (3 sesiones semanales) ya que una recuperación insuficiente entre sesiones de entrenamiento pueden limitar las adaptaciones simultáneas de fuerza y resistencia. La fatiga residual de una sesión de resistencia aeróbica previa produciría una disminución de la calidad del entrenamiento en la sesión posterior de fuerza, comprometiendo la capacidad del sistema neuromuscular para producir fuerza y/o forzando a reducir el volumen absoluto de entrenamiento de fuerza que pueda ser realizado en tales condiciones.

- o Programar las sesiones de fuerza antes de las sesiones de resistencia o, cuando no fuese posible, separar ambas sesiones de entrenamiento al menos 6-8 horas para permitir una adecuada reposición del glucógeno muscular.

- Alcanzar mejoras significativas del VT2 y el VO_{2max} en deportistas de élite en cortos periodos de entrenamiento (5 semanas), requirió una acumulación de carga sobre la zona específica de entrenamiento superior al 50%. Igualmente parece necesario realizar una acumulación de carga superior al 35% para garantizar el mantenimiento de los niveles de VT2 en aquellas fases donde no se desarrolle como objetivo prioritario. Los niveles de fuerza dinámica máxima y la velocidad ante cargas de máxima potencia registraron aumentos de su rendimiento con una concentración de carga de entrenamiento de fuerza sobre estos objetivos superior al 80%, mientras que una acumulación de carga del 20% no permitió mantener las adaptaciones de fuerza dinámica máxima cuando no se estableció como objetivo prioritario de la fase.

- Los resultados obtenidos en la fuerza dinámica máxima, unidos a los elevados valores de VO_{2max} y VO_2VT2 hallados en este estudio confirman los grandes requerimientos de potencia aeróbica y de fuerza en las pruebas de piragüismo incluidas en el programa olímpico.

- Cortos periodos de cesión de entrenamiento produjeron mayores descensos de la fuerza y potencia muscular en sujetos de alto nivel con gran experiencia en el entrenamiento de fuerza y resistencia, comparado con la estrategia de reducción de entrenamiento (una sesión de entrenamiento de fuerza y dos de resistencia semanales). Además, la potencia muscular parece ser especialmente susceptible a los periodos de desentrenamiento en deportistas de alto nivel, produciendo pérdidas con mayor celeridad que sobre la fuerza máxima. Estos resultados pueden sugerir la necesidad de incorporar programas de reducción de entrenamiento para evitar excesivas pérdidas en el rendimiento neuromuscular en las fases de recuperación mayores de 2-3 semanas.

- Igualmente, estas fases de reducción de entrenamiento paraecen ser efectivas para atenuar los adversos efectos del desentrenamiento obervados tras la cesión completa de entrenamiento en las variables fisiológicas y especificas de rendmiento en piragüismo como el VO_{2max}, FC_{VT2}, FP_{max}, FP_{VT2}, V_{max}, Pw_{max}, y la Pw_{VT2} en palistas de élite mundial.

- Ambas estrategias de recuperación, especialmente la reducción de entrenamiento, parecen facilitar los procesos anabólicos y regenerativos del organismo de cara al comienzo de una nueva temporada de entrenamiento y competición.

- La composición corporal de los piragüistas de élite presenta fluctuaciones importantes durante las diferentes fases de entrenamiento, competición y recuperación. Resulta destacable que la masa corporal no parece sufrir cambios significativos a lo largo de la temporada, y que son los componentes de masa grasa y masa libre de grasa las que presentan importantes variaciones en función de la carga global y la orientación del entrenamiento.

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ANEXO 1

PUBLICACIONES EN VERSIÓN ORIGINAL

I-III

Manuscript I

“Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle”

Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle

European Journal of Applied Physiology 2009

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Abstract

This study was undertaken to analyze changes in selected cardiovascular and neuromuscular variables in a group of elite kayakers across a 12-week periodized cycle of combined strength and endurance training. Eleven world-class level paddlers underwent a battery of tests, and were assessed four times during the training cycle (T0, T1, T2, T3). On each occasion subjects completed an incremental test to exhaustion on the kayak ergometer to determine maximal oxygen uptake (VO_{2max}), second ventilatory threshold (VT2), peak blood lactate, paddling speed at VO_{2max} (PS_{max}) and at VT2 (PS_{VT2}), stroke rate at VO_{2max} and at VT2, heart rate at VO_{2max} and at VT2. One-repetition maximum (1RM) and mean velocity with 45% 1RM load ($V_{45\%}$) were assessed in the bench press (BP) and prone bench pull (PBP) exercises. Anthropometric measurements (skinfold thicknesses and muscle girths) were also obtained. Training volume and exercise intensity were quantified for each of three training phases (P1, P2, P3). Significant improvements in VO_{2max} (9.5%), VO_2 at VT2 (9.4%), PS_{max} (6.2%), PS_{VT2} (4.4%), 1RM in BP (4.2%) and PBP (5.3%), $V_{45\%}$ in BP (14.4%) and PBP (10.0%) were observed from T0 to T3. A 12-week periodized strength and endurance programme with special emphasis on prioritizing the sequential development of specific physical fitness components in each training phase (i.e. muscle hypertrophy and VT2 in P1, and maximal strength and aerobic power in P2) seems effective for improving both cardiovascular and neuromuscular markers of highly trained top-level athletes.

Keywords Concurrent training; resistance training; endurance performance; canoeing; exercise testing; periodization.

Introduction

It is generally accepted by coaches and sport scientists that to maximize physiological adaptations and to avoid overtraining, proper handling of training programme variables, including the intensity, frequency and volume of exercise, is required. This is especially important in sports where both endurance and strength need to be simultaneously enhanced to optimize performance (e.g. kayaking). Because strength and endurance training elicit distinct and often divergent adaptive mechanisms (Nader 2006; Sale et al. 1990a), the concurrent development of both fitness components in the same training regime can lead to conflicting neuromuscular adaptations.

This potential conflict has been referred to as an 'interference phenomenon' and it was first described by Hickson (1980), who observed compromised strength development when strength and endurance training were applied concurrently. However, results of subsequent research have been equivocal, with studies both supporting (Bell et al. 2000; Craig et al. 1991; Dudley and Djamil 1985; Hennesy and Watson 1994; Kraemer et al. 1995) and questioning (Häkkinen et al. 2003; Hunter et al. 1987; McCarthy et al. 1995, 2002; Sale et al. 1990a) the universal nature of such interference. Several factors such as initial training status of the subjects, exercise mode, volume, intensity and frequency of training, scheduling of sessions, and dependent variable selection may influence the level of interference and explain the contradictory results of these studies (Docherty and Sporer 2000; Leveritt et al. 1999; Sale et al. 1990a). A detailed examination of the existing research on this topic seems to indicate that the volume, especially the frequency of training, may play a critical role in the adaptations consequent to concurrent training (Häkkinen et al. 2003; Izquierdo et al. 2005; McCarthy et al. 2002).

For example, most of the studies have reported concurrent training to be detrimental for strength gains only when training frequency was higher than three days per week (Dudley and Djamil 1985; Hennesy and Watson 1994; Hickson 1980; Hunter et al. 1987; Kraemer et al. 1995). The neuromuscular mechanisms related to power production and explosive strength development seem to be the most affected by the simultaneous training of strength and endurance (Dudley and Djamil 1985; Häkkinen et al. 2003; Hennesy and Watson 1994; Kraemer et al. 1995). By comparison, the majority of current research supports the contention that concurrent training does not alter the ability to adapt to endurance training (Docherty and Sporer 2000; Hickson et al. 1988). Indeed, a number of studies have concluded that the addition of resistance training to ongoing exercise regimens of well-trained endurance athletes is beneficial and results in improved endurance performance (Hickson et al. 1988; Mikkola et al. 2007; Millet et al. 2002). Nevertheless, the question of which is the best way of sequencing sessions targeted at different goals, for the simultaneous development of strength and endurance, remains complex and not satisfactorily solved.

There exists some evidence to support that periodized resistance training programmes can result in greater strength gains than non-periodized programmes (Fleck 1999; Willoughby 1993). Non-linear or undulating models in which short periods of high volume are alternated with short periods of high intensity training are thought to optimize strength gains (Baker et al. 1994). Unfortunately, there are very few studies in the scientific literature that have explored the effects of periodized training on sports with great demands of both strength and endurance, and even fewer that have done so using elite athletes as subjects. Based on evidence from existing research (Docherty and Sporer, 2000; Leveritt et al. 1999, 2000; Sale et al. 1990b; Sporer and Wenger 2003), we chose to structure a periodized programme aimed at minimizing the possible interference effects in the simultaneous training of the strength and endurance components of physical fitness. Therefore, it was the purpose of the present study to examine the effects brought about by a 12-week periodized programme of combined strength and endurance training on selected neuromuscular and cardiovascular parameters in a group of world-class level kayakers.

Methods

Subjects

Eleven male world-class, flat-water kayak paddlers (all of whom were finalists at the World Championships, including two Olympic gold-medallists) volunteered to take part in this study. Mean (SD) characteristics of participants were as follows: age 26.2 (2.8) years; height 1.83 (0.07) m; body mass 86.2 (5.2) kg; training experience 12.4 (2.1) years, annual paddling volume 4,220 (354) km. Subjects had at least three years of familiarization with the testing procedures used in this investigation, and they followed their respective training routines under strict supervision from coaches and sport scientists from the Royal Spanish Canoeing Federation. No physical limitations or musculoskeletal injuries that could affect training were reported. Kayakers underwent a complete medical examination (including ECG) that showed all were in good health condition. The study, which was conducted according to the declaration of Helsinki, was approved by the *Bioethics Commission* of the University of Seville, and written informed consent was obtained from all subjects prior to participation.

Previous training

Prior to entering the experimental phase of this study, participants had completed a 5-wk transition period during which no specific paddling or resistance training was undertaken. Only some recreational physical activities (sport games plus cycling or swimming at low intensities) were performed.

Experimental design and testing sequencing

All subjects followed the same training programme during the 12-wk duration of the study. Subjects reported to the laboratory on four separate occasions (T0, T1, T2 and T3) throughout the intervention in order to assess the selected cardiovascular, neuromuscular and anthropometric parameters. Testing was completed on three consecutive days: anthropometry and maximal incremental exercise test on the kayak ergometer (day 1), one repetition maximum (1RM) strength (day 2) and power testing (day 3). 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, and all testing sessions were performed at the same time of day (10-12 h) and under similar environmental conditions (20-22 ºC and 55-65% humidity. In a pilot study, the inter-test reliability for measuring maximal oxygen uptake (VO_{2max}), second ventilatory threshold (VT2), and HR at VO_{2max} (HR_{max}) was assessed by performing two incremental paddling tests to volitional exhaustion, separated by three weeks, on a kayak ergometer on twelve elite junior male kayakers, of international competitive level in the 500 m and 1000 m sprint flat-water events. No significant differences were observed between the 3-

week measurements in the endurance variables analysed. Paddling testing variables showed reliability coefficients ranging from 0.92 to 0.98. The coefficients of variation (CV) for VO_{2max}, VT2, and HR_{max} ranged between 3.2% and 5.1%. The test-retest intraclass correlation coefficients for all strength/power variables used in this study were greater than 0.93 and CV ranged from 0.9% to 2.9%. No control group was used because including such a group while studying elite athletes could be considered highly unethical since withholding important training stimuli would be detrimental to the athletes' progress (Kraemer 2005).

Anthropometry

Anthropometric measurements included: standing height, body mass, skinfold thicknesses (triceps brachii, subscapular, suprailiac, abdominal, anterior thigh, medial calf, supraspinale and biceps brachii), and muscle girths (chest, forearm, thigh, calf), and were performed by the same experienced investigator in accordance with guidelines from the International Society for the Advancement of Kineanthropometry (ISAK). 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 thicknesses and muscle girths were assessed, respectively, by using a skinfold caliper (accurate to 0.2 mm) and flexible measurement tape (1 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 $km \cdot h^{-1}$, subjects completed an incremental paddling test to volitional exhaustion on a kayak ergometer (Dansprint ApS, Denmark). The first stage was set at a speed of 11.5 $km \cdot h^{-1}$, and the speed increment was 0.5 $km \cdot h^{-1}$ each minute. Each kayaker freely adjusted 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 HR telemetry (S610i, Polar Electro Oy, Finland) and recorded every 5 s. Paddlers were encouraged to make a maximal effort and complete as many stages as possible. The test concluded when: a) the subject voluntarily stopped paddling, or b) 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. VT2 was determined from gas exchange measurements using the criteria of an increase in both ventilatory equivalents ($V_E \cdot VO_2^{-1}$ and $V_E \cdot VCO_2^{-1}$ ratios) 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. VO_{2max} was defined as the average of the two highest single consecutive 15-s VO_2 mean values attained towards the end of the test. The following variables were determined for each paddler: O_2 uptake at VT2 (VO_2 at VT2), VT2 as a percentage of VO_{2max} (VT2(%VO_{2max})), HR_{max}, HR at VT2 (HR_{VT2}), SR at VO_{2max} (SR_{max}), SR at VT2 (SR_{VT2}), paddling speed at VT2 (PS_{VT2}) and paddling speed at VO_{2max} (PS_{max}). Capillary whole blood samples were taken from each kayaker's earlobe during test recovery (minutes 1, 3, 5, 7 and 10) to determine peak lactate concentration ($[La^-]_{peak}$) using a miniphotometer (LP20, Dr. Lange, France).

Maximal strength and muscle power assessment

1RM was determined in the bench press (BP) and prone bench pull (PBP) using free weights. These were chosen because they are typical resistance training exercises used in the sport of canoeing, and are useful to assess strength and power in the opposing upper-body muscle actions of pushing and pulling. Warm-up consisted of 5-min of stationary cycling at a self-selected easy pace, followed by 5-min of static stretching and upper-body joint mobilization exercises. After a 3-min recovery, a set of 6 repetitions with the estimated 60% 1RM load, and another set of 2-3 repetitions with the estimated 80% 1RM load for each exercise were performed. Thereafter, each subject performed 3-5 more one-repetition sets with 5-min recovery pauses until his 1RM load could be determined with a precision of 2.5 kg. After two failed attempts at the same load, the test was terminated. The heaviest load that each subject could properly lift, without any external help, was considered to be his 1RM.

On the following day, mean concentric velocity with 45% of the previously determined 1RM load ($V_{45\%}$) was assessed for both exercises. This load was chosen since it has been proved to be very close to the load that maximizes the average mechanical power output for isoinertial upper-body resistance exercises (Cronin and Sleivert 2005, Izquierdo et al. 2002). After an identical warm-up, subjects performed 2 sets of 3 repetitions with the 45% 1RM load, using a 5-min recovery pause between sets. Mean velocity was recorded by means of a linear position transducer (MuscleLab, Ergotest Technology, Oslo, Norway). The mean velocity of the three best repetitions for each subject was registered as the $V_{45\%}$. In the BP, subjects lay supine on a flat bench, with their feet resting flat on the floor, and hands placed on the barbell slightly wider (5-7 cm) than shoulder width. After lowering the barbell to the chest, they pushed upwards, at maximum velocity, to the full extension of their elbows. The subjects were not allowed to bounce the bar off their chests or raise the shoulders or trunk off the bench. If this occurred, the trial was rejected and subsequently repeated. In the PBP, paddlers were instructed to lie prone and place their chin on the padded edge of a high bench. The pulling phase began with both elbows in full extension while the barbell was grasped with hands shoulder-width apart or slightly wider (4-5 cm). The participants were instructed to pull with maximum effort until the barbell struck the underside of the bench, after which it was again lowered to the starting position. In both exercises, subjects' positions on the bench and grip widths were measured so that they could be reproduced on every lift.

Periodized training programme

The training cycle was divided into three consecutive training phases. Phases one (P1; from T0 to T1) and two (P2; from T1 to T2) had a duration of 5 weeks, while the final phase (P3; from T2 to T3) lasted only 2 weeks. Two prioritized targets per fitness component (endurance and strength) were chosen to selectively work upon in each phase: P1, VT2 and muscle hypertrophy; P2, maximal aerobic power and maximal strength; and P3, specific kayaking racing pace and maximal power output. Testing was undertaken in the first week of each phase (T0, T1, T2) and again at the 13^{th} week, right after the completion of the training programme (T3). Athletes exercised daily, except one full rest day per week. Strength training sessions were preferentially arranged prior to endurance sessions; when this was not possible, sufficient recovery time (6-8 h) was allowed before undertaking resistance training. Compliance with training requirements was excellent for all participants.

Endurance training

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_{2max}; and zone 3 (Z3), high intensity, between 90% and 100% of VO_{2max}. No higher, supramaximal intensities were used in this study. A description of the characteristics of endurance exercise modes used for training each intensity zone is provided in Table 1. The relative contribution of each of these intensities to the total training volume for each phase was markedly different (Fig. 1). Volume and intensity were carefully controlled and quantified for each training session throughout the full 12-wk training cycle. The main variables used for endurance training monitoring were: time spent (hours) and distance covered (km) for volume; and HR and paddling speed for intensity. Distance and speed were registered by means of a GPS receiver (Garmin 201, Garmin Ltd., USA). Total time devoted to endurance training was 52.7 ± 1.9 h in P1, 49.5 ± 1.5h in P2 and 21.5 ± 0.8h in P3. Number of endurance training sessions per week ranged from 10 to 15.

Table 1. Description of the endurance training modes used for each intensity zone.

Intensity Zone	Total Volume (min)	Sets	Repetitions	Work (min)	Rest Period (min)	Intensity (%VO_{2max})
Z1	70 - 120	1	1-3	20 - 90	1-3	70% - 80%
Z2	40 - 90	1-4	1-10	5-20	1-4	80% - 90%
Z3	20 - 60	2-5	4-8	1-8	2-8	90% - 100%

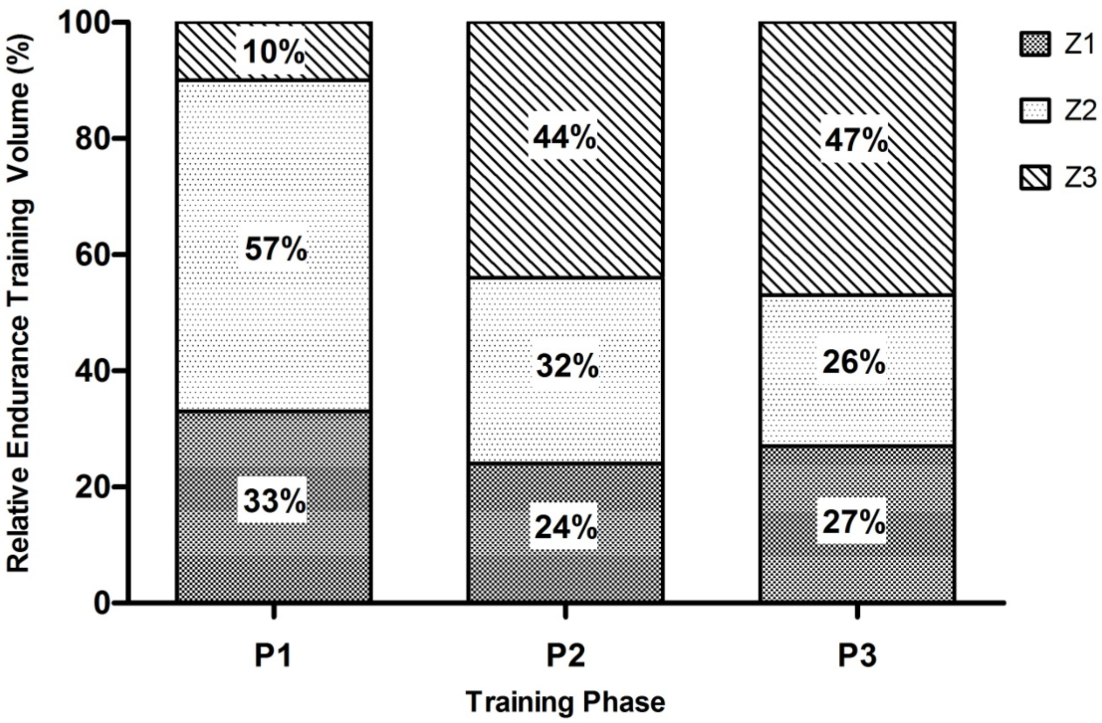

Fig. 1. Relative contribution of each exercise intensity zone to the total endurance training time performed in each phase. Z1: light intensity, below VT2; Z2: moderate intensity, between VT2 and 90% of VO_{2max}; Z3: high intensity, between 90% and 100% of VO_{2max}.

Resistance training

Exercise type, loading intensity, number of sets and repetitions, as well as rest pauses were different for each training phase (Table 2), and subjects completed three strength training sessions per week. Training to repetition failure was deliberately avoided, and paddlers were constantly encouraged to perform each repetition at maximal concentric velocity, regardless of the load being lifted. Eccentric actions were always performed in a slow controlled manner, lowering the weights in approximately 3 s. In maximal power training sessions (P3), each set was terminated when mean velocity decreased by more than 10% of the best (fastest) repetition's mean concentric velocity. In all strength training sessions, volume was recorded using total load lifted (kg) and number of repetitions completed. Intensity was assessed as percentage of 1RM and mean concentric velocity in each repetition as measured by the linear position transducer. All training was supervised by professional coaches with several years of experience in the training of kayakers and canoeists. Total strength training volume was 15.6 ± 0.8 h and 2,430 ± 42 repetitions during P1, 13.2 ± 0.7 h and 660 ± 13 repetitions during P2, and 8.4 ± 0.5 h and 520 ±

14 repetitions during P3. The relative contribution of each strength training type to the total training volume in each phase is shown in Fig. 2.

Table 2. Types and characteristics of resistance training

	Exercises	Sets	Repetitions	Load (%1RM)	Rest
Hypertrophy	Bench Press, Prone Bench Pull, Squat, Shoulder press, Pull ups	4 - 5	8 - 10	70% - 75%	2 min
Maximal Strength	Bench Press, Prone Bench Pull, Squat	3 - 4	3 - 4	85% - 90%	4 min
Maximal Power	Bench Press, Prone Bench Pull	4 - 5	5 - 8*	45%	4 min

* Each subject performed the maximum possible number of repetitions until mean concentric velocity dropped by more than 10% of the fastest repetition velocity within that set.

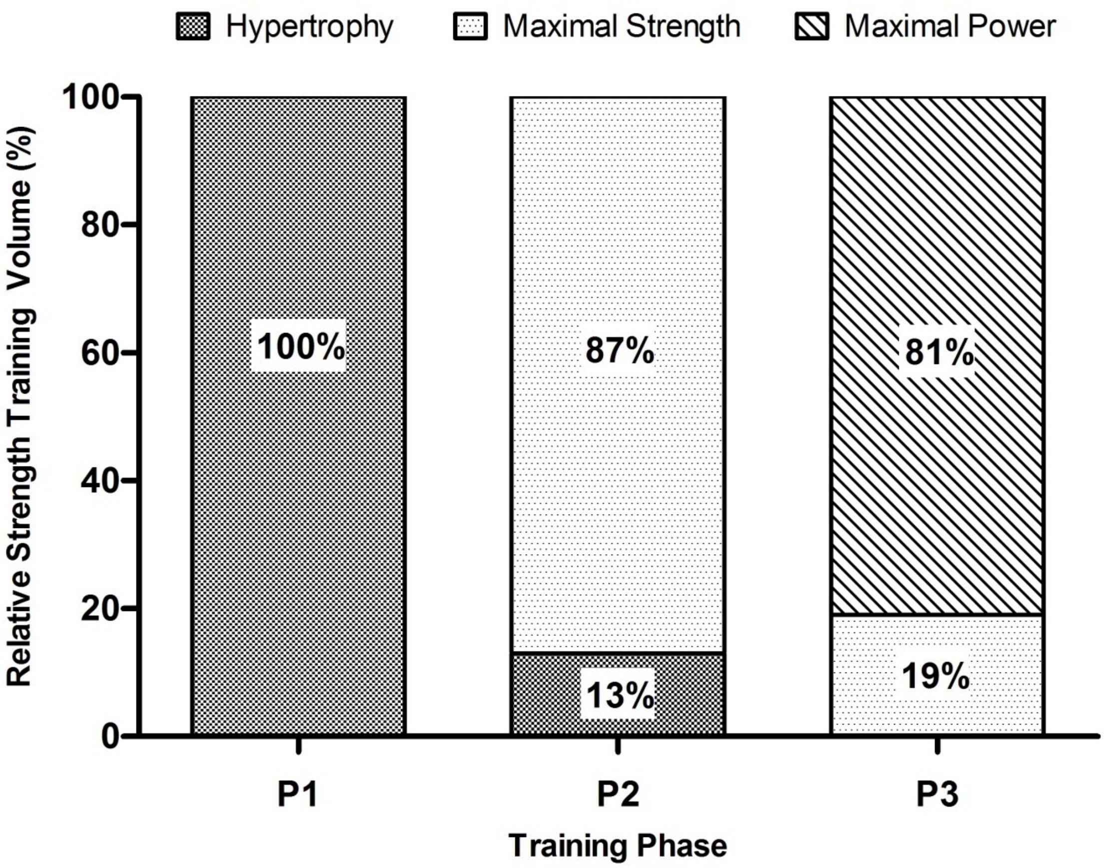

Fig. 2. Relative contribution of each strength training type used in this study to the total training volume in each phase.

Statistical analysis

Standard statistical methods were used for the calculation of mean values and standard deviations (SD). The Kolmogorov-Smirnov test was applied to determine the nature of the data distribution. Because a normal distribution was confirmed, repeated measures ANOVA was used to evaluate changes in selected variables over the 12-wk training period (T0-T1-T2-T3). Tukey's *post-hoc* test was used to identify the source of any significant differences. Significance was accepted at the P < 0.05 level.

Results

Anthropometric changes

Changes in anthropometric measurements are reported in Table 3.

Table 3. Changes in anthropometric parameters.

	T0	T1	T2	T3
Body mass (kg)	86.0 ± 4.4	88.1 ± 4.8	85.9 ± 4.5	85.6 ± 4.6
Sum of 4 skinfolds (mm)	35.5 ± 2.9	34.0 ± 2.3	29.0 ± 2.1#	34.3 ± 2.3£
Sum of 8 skinfolds (mm)	67.4 ± 5.1	63.5 ± 4.3	53.5 ± 3.9#	63.8 ± 4.5£
Thigh girth (cm)	56.4 ± 1.8	58.2 ± 1.6	57.6 ± 1.6	57.3 ± 1.8
Chest girth (cm)	105.2 ± 3.8	109.2 ± 3.9*	107.5 ± 3.4	107.1 ± 3.9
Forearm girth (cm)	28.6 ± 1.1	29.3 ± 1.1	28.9 ± 1.3	28.7 ± 1.1
Calf girth (cm)	36.0 ± 0.7	37.2 ± 0.9	37.0 ± 1.0	37.0 ± 0.9

Data is expressed as mean ± SD
4 skinfolds: triceps brachii, subscapular, supraspinale, abdominal
8 skinfolds: 4 skinfolds + biceps brachii, suprailiac, anterior thigh, medial calf
* Significantly different (P < 0.05) when comparing T0 to T1
# Significantly different (P < 0.05) when comparing T1 to T2
£ Significantly different (P < 0.05) when comparing T2 to T3

Cardiovascular and endurance performance changes

VO_{2max} increased by 3.5% from T0 to T1 ($P = 0.063$) and by 5.3% from T1 to T2 ($P < 0.01$), while no significant differences in VO_{2max} were observed from T2 to T3. VO_2 at VT2 increased significantly between T0 and T1 (12.4%, $P < 0.01$) but decreased by 4.3% from T1 to T2 ($P < 0.05$). VT2 (%VO_{2max}) significantly increased from T0 to T1 (8.6%, $P < 0.01$), while it decreased 9.0% ($P < 0.01$) when comparing T1 to T2. PS_{max} improved at T1 (2.1%, $P < 0.05$), T2 (2.0%, $P = 0.068$) and T3 (2.0%, $P < 0.05$). No significant differences were observed for the rest of the variables analyzed (HR_{max}, HR_{VT2}, SR_{max}, SR_{VT2}, and $[La^-]_{max}$) (Table 4 and Fig. 3).

Table 4. Changes in selected physiological and performance variables across the 12-wk training programme.

	T0	T1	T2	T3
PS_{max} ($km \cdot h^{-1}$)	14.5 ± 0.3	14.8 ± 0.2*	15.1 ± 0.3	15.4 ± 0.2$^{£\,†}$
PS_{VT2} ($km \cdot h^{-1}$)	13.6 ± 0.2	13.9 ± 0.2*	14.1 ± 0.2	14.2 ± 0.3†
$[La^-]_{peak}$ ($mmol \cdot L^{-1}$)	12.5 ± 3.3	11.8 ± 2.5	12.8 ± 2.2	13.0 ± 2.8
HR_{max} (beats $\cdot min^{-1}$)	194 ± 8	188 ± 8	189 ± 10	189 ± 7
HR_{VT2} (beats $\cdot min^{-1}$)	175 ± 7	172 ± 7	171 ± 6	172 ± 6
SR_{max} (strokes$\cdot min^{-1}$)	104 ± 5	101 ± 9	101 ± 7	103 ± 8
SR_{VT2} (strokes$\cdot min^{-1}$)	88 ± 4	84 ± 6	85 ± 5	85 ± 7

Data is expressed as mean ± SD
* Significantly different ($P < 0.05$) when comparing T0 to T1
£ Significantly different ($P < 0.05$) when comparing T2 to T3
† Significantly different ($P < 0.05$) when comparing T0 to T3

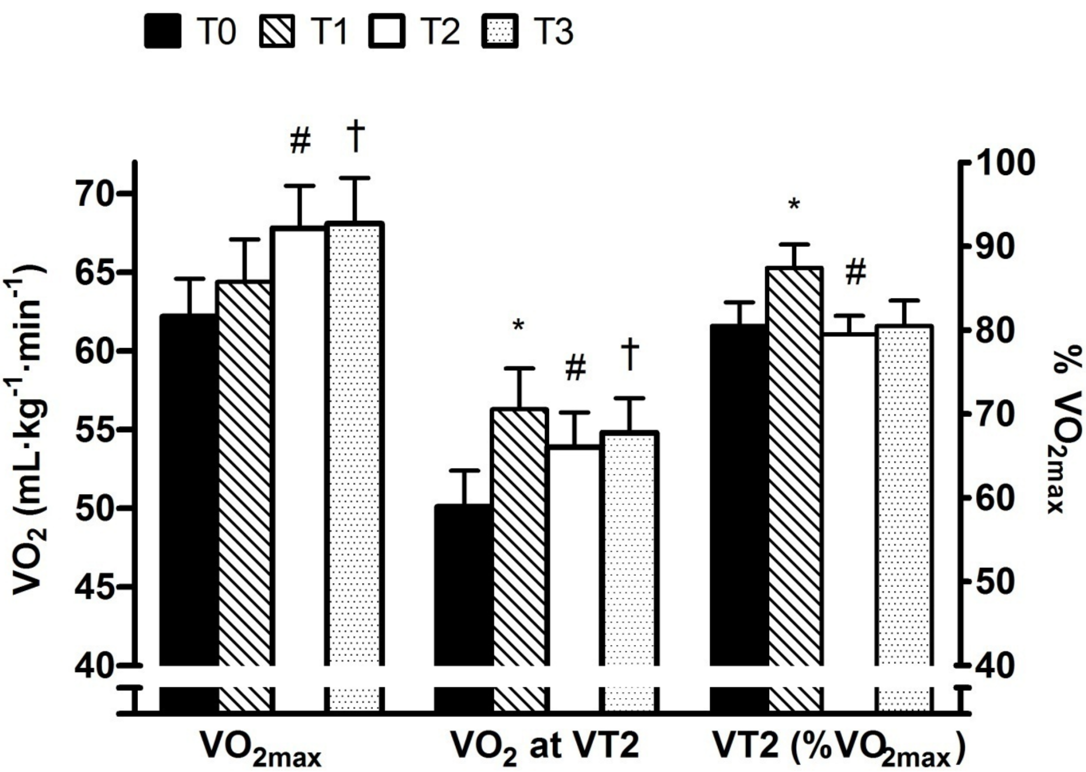

Fig. 3. Changes in VO_{2max} and VT2 across the 12-wk training programme. Data is presented as mean ± SD. *Significantly different (P < 0.05) from T0 to T1. #Idem (P < 0.05) from T1 to T2. #Idem (P < 0.05) from T1 and T2. †Idem (P < 0.05) from T0 to T3.

Strength and power changes

From T0 to T1, 1RM improved significantly (9.7% and 7.7% for BP and PBP respectively, P < 0.01), while $V_{45\%}$ remained unchanged in both bench press and prone bench pull exercises. Between T1 and T2, no significant changes were observed in 1RM values, while $V_{45\%}$ improvement was close to statistical significance (5.3%, P = 0.077 for BP and 4.6%, P = 0.082 for PBP). From T2 to T3, 1RM values significantly decreased by 4.6% and 4.5 % (P < 0.05) respectively for BP and PBP. Simultaneously, $V_{45\%}$ significantly improved by 11.0% (P < 0.01) in BP and 7.1% (P < 0.01) in PBP. When comparing T0 and T3 values for these variables, significant improvements were found in 1RM values for BP (4.2%, P < 0.05) and PBP (5.3%, P < 0.05). Significant increases were also observed in $V_{45\%}$ for both bench press (14.4%, P < 0.001) and prone bench pull exercises (10%, P < 0.001) (Fig. 4).

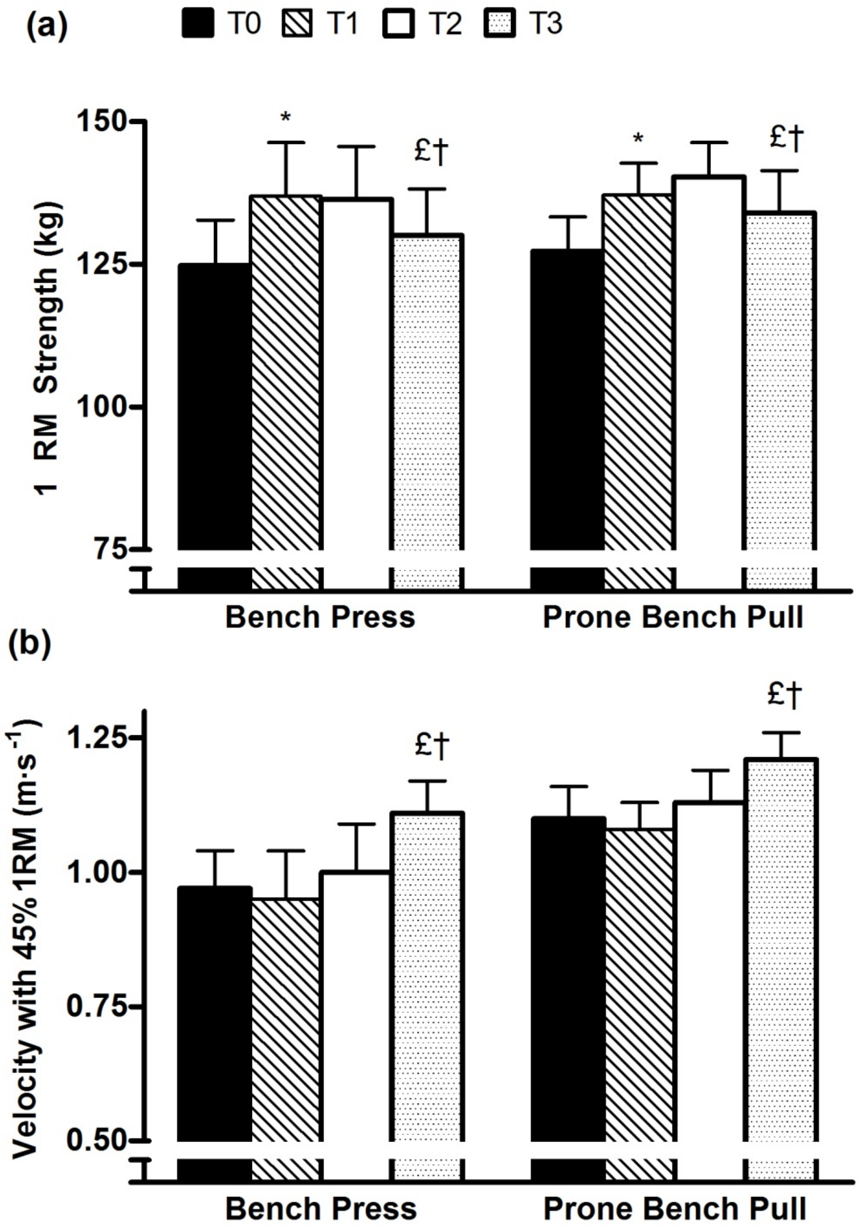

Fig. 4. Changes throughout the 12-wk training programme in 1RM strength **(a)** and mean concentric velocity attained with 45% 1RM load **(b)** in the bench press and prone bench pull exercises. Data is presented as mean ± SD. *Significantly different ($P < 0.05$) from T0 to T1. $^{£}$Idem ($P < 0.05$) from T2 to T3. †Idem ($P < 0.05$) from T0 to T3.

Discussion

This study details the changes in selected endurance, anthropometric and strength-related parameters of world-class level kayakers across a 12-wk periodized training cycle. The results are important and unique, due to the internationally elite level of the athletes, the very high demands of strength and endurance of their sport discipline, as well as the scarcity of this type of study in the literature. The main finding of the present study was that 12-wk of periodized training was effective for inducing significant gains in both strength and muscle power, as well as endurance performance, showing that it is possible to simultaneously develop these different physical fitness components in a relatively short period of time and at a world-class level of performance.

It has been previously reported that a properly designed and implemented periodization scheme could be the best approach to minimize the potential interference effects in simultaneous strength and endurance training (Baker 2001; Docherty and Sporer 2000). However, little is known about what would be the optimal structure for such periodization during sports requiring both strength and aerobic performance (e.g. Olympic kayaking). According to the model proposed by Docherty and Sporer (2000), we chose to prioritize the fitness components to sequentially develop in each training phase so that potential interferences in the simultaneous training of strength and endurance could be minimized. In particular, the periodized training programme used in this study deliberately avoided mixing the specific training objectives of muscle hypertrophy (i.e. strength training objective at P1) and maximal aerobic power (i.e. endurance training objective at P2) because these are thought to be two modes of training that lead to opposite physiological adaptations at the peripheral level that prevent the body from optimally and simultaneously adapting to both of them (Leveritt 1999). Thus, while hypertrophy training would be attempting to increase contractile protein synthesis in the muscle, causing considerable metabolic and hormonal stress at the cellular level, training for aerobic power would require the muscle to increase its oxidative capacity (Docherty and Sporer 2000; Sale 1990a). On the contrary, training at lower aerobic intensities (75-85% VO_{2max}), such as those usually employed to improve the VT2 would induce more centrally mediated adaptations that would be expected to cause much less interference with the method of strength development via muscle hypertrophy (P1). The cited model also predicts less interference when concurrently training for maximal strength/power and aerobic power (P3), because the training stimulus for increasing strength would be mainly directed at the neural system (increased motor unit firing rate and changes in synchronization, recruitment of higher threshold motor units, etc.), not placing high metabolic demands on the muscle. Therefore, it appears that the manipulation of training intensity in each training phase is critical to avoid potential interferences in concurrent training (Docherty and Sporer 2000).

Although the total volume of endurance training was very similar for the first 5-wk training phases (52.7 h for P1 and 49.5 h for P2), training intensity was markedly different. While in P1 most of the training volume was devoted to improving the VT2 (57% of total training time in Z2), aerobic power development was favoured in P2 (44% of total training time in Z3). The specificity of training appears to be reflected in the observed cardiovascular changes observed within every training phase. Thus, VO_2 at VT2 was the variable that improved the most in P1 (12.4%), whereas VO_{2max} increased more than any other cardiovascular variable in P2 (5.3%) (Fig. 3). The VO_{2max} mean value of 68.1 $mL·kg^{-1}·min^{-1}$ reached after the 12-wk training intervention is significantly higher than that obtained by other authors with high-level kayakers using similar ergometry testing protocols (i.e. mostly in the 54-60 $mL·kg^{-1}·min^{-1}$ range) (Bishop et al. 2002; Fry and Morton 1991; Tesch et al. 1983; Van Someren and Oliver 2002). Although the endurance training performed in P1 was not directly focused towards the development of aerobic power (Fig. 1), the almost significant improvement in maximal aerobic power (3.5%) after this training phase (Fig. 3) is probably due to subjects exhibiting a particularly low initial level because of the previous 5-wk transition period. As mentioned above, a 5.3% mean improvement in VO_{2max} was obtained in P2, after increasing training time devoted to aerobic power (i.e. from 5.3 h to 21.8 h of training in Z3) for these already highly trained athletes. The observed changes in VO_{2max} in only 12 weeks of training (9.5% increase from T0 to T3; Fig. 3) are of similar magnitude to those of 8.0% described in a previous study (Tesch et al. 1976) with international-level kayakers and canoeists after a longer training period (8 months).

Similarly, the specificity of endurance training around the VT2 during P1 (57% of total training time in Z2, Fig. 1) brought about important increases in VO_2 at VT2 (12.4%). In P2, coinciding with an important reduction in training time spent at Z2 (only 32% in this intensity zone), VO_2 values at VT2 significantly decreased by 4.3%; whereas no changes for this variable were observed in P3. After completing the 12-wk training cycle, VT2 (%VO_{2max}) was identical to the starting value (80.5%), despite the fact that VO_2 at VT2 was significantly higher (increasing from 50.1 to 54.8 $mL·kg^{-1}·min^{-1}$ from T0 to T3) (Fig. 3).

Variables closely related to actual kayaking performance, such as PS_{max} and PS_{VT2} increased steadily and similarly throughout the training cycle until reaching an improvement of 6.2% and 4.4% between T0 and T3, respectively (Table 4). It is noteworthy that PS_{max} improved from 15.1 to 15.5 $km \cdot h^{-1}$ in the final two weeks (P3). The peak blood lactate concentration found after the incremental test to exhaustion on the kayak ergometer (13.0 ± 2.8 $mmol \cdot L^{-1}$) was comparable to the values reported in the literature (Bishop et al. 2002, Tesch et al. 1976, 1983) for similar top-level kayakers (i.e. 13-16 $mmol \cdot L^{-1}$), and occurred at between 5 and 7 min of recovery in all subjects.

The improvements in 1RM values for the bench press exercise (9.7%; Fig. 4), after 5-wk of hypertrophy-oriented strength training performed in P1, are comparable to those described for this exercise for moderately strength-trained athletes following similar concurrent training routines in elite junior basketball and soccer players (from 5.2 to 9.6%) (Drinkwater et al. 2005, 2007), or handball players (16%) (Marques and González-Badillo 2006) after 6-wk training. This notable increase in maximal strength was obtained even though only very modest levels of hypertrophy were detected in such a short training phase; thus, chest girth was the only variable to significantly increase during this period (Table 3). Unfortunately, MRI or other more sensitive measurements to ascertain the extent of possible hypertrophic changes were not performed in the present study. The greatest improvements in $V_{45\%}$ (11% in BP and 7% in PBP) clearly occurred after P3, where 80% of total resistance-training volume was spent on specifically working with maximal power output loads for upper-body exercises (Fig. 4). During this type of training, the number of repetitions performed in each set was carefully controlled by monitoring the velocity of each repetition and giving immediate feedback to the athlete. The set was stopped when velocity dropped by more than 10% of the fastest repetition mean concentric velocity (Table 2). This made it possible to attain very high power output values in only a few selected repetitions, such as has already been suggested by some authors (Baker and Newton 2007; Izquierdo et al. 2006b; Tidow 1995) as an effective strategy for improving maximal power in highly trained elite athletes. By contrast, maximal dynamic strength decreased considerably in P3 (4.5% in both exercises; Fig. 4) even though 20% of total training time during this phase was of maximal strength type (Fig. 2). This could be explained by the significantly reduced volume and intensity of training during this final tapering phase, perhaps suggesting that high-intensity stimuli are needed in order to maintain maximal strength gains in these highly trained athletes. The 1RM strength values, together with the high VO_{2max} and VO_2 at VT2 found in this study confirm the huge requirements of aerobic power and strength of Olympic sprint kayaking.

Despite the time devoted to endurance training being, on average, more than triple that of resistance training, strength and power markers improved consistently throughout the study. Together with the above-mentioned strategy of prioritizing the development of two target fitness components (i.e. one for strength and another for endurance) in each training phase, the simultaneous improvement in strength and endurance markers observed in the present study may be explained by other factors which we believe helped to reduce conflicting adaptations in the concurrent training of strength and endurance. One important aspect was controlling for training volume and, especially, limiting the frequency of resistance training to only three sessions per week because, as already addressed in the introduction, higher frequencies have proved to compromise strength gains in most concurrent training studies. Research has also highlighted the importance of the order and timing of the aerobic and strength training sessions in order to minimize possible interference effects (Leveritt et al. 1999, 2000; Sale et al. 1990b; Sporer and Wenger 2003). Thus, insufficient recovery between training sessions might limit simultaneous adaptations to strength and endurance training. Residual fatigue from a previous aerobic session could cause a reduction in the quality of subsequent strength training by compromising the ability of the neuromuscular system to rapidly develop force (Leveritt et al. 1999) and/or reducing the absolute volume of strength training that could be performed in such condition (Sale et al. 1990b). Additionally, acute changes in metabolic activity have been reported to be altered by a preceding bout of endurance exercise (Leveritt et al. 2000). Consequently, and following the suggestions outlined by Sporer and Wenger (2003) we decided to schedule strength sessions before endurance sessions or, when not feasible, to separate both types of training sessions by at least 6-8 h to allow for restoration and glycogen repletion.

Two other aspects that we purposely introduced in the design of the training programme were the avoidance of strength training sessions leading to muscle failure and the emphasis placed on performing each repetition explosively, with maximal intended concentric velocity. These measures are based on suggestions from previous research (Cronin and Sleivert 2005; Folland et al. 2002; Izquierdo et al. 2006a), and are aimed at maximizing adaptations in the neural component of strength, as well as trying to avoid excessive fatigue or mechanical and metabolic strain which could negatively influence the quality of subsequent training sessions. In the study of Sale et al. (1990b) although same day concurrent resistance and aerobic training induced very similar levels of muscle hypertrophy to those obtained when training strength and endurance on different days, strength gains were significantly higher in the latter case. Therefore, it seems likely that neural adaptations are impaired when combining strength and endurance in the same training session, so that to improve neuromuscular performance and make the most of strength training, sessions must be undertaken in a well-rested, unfatigued state.One may also speculate that similarly to the concurrent strength and endurance programme performed in the present study, the shortest events of kayaking, canoeing and rowing could benefit from periodized programmes where emphasis is placed on developing maximal strength and maximal muscle power in certain phases of the training cycle.

A final aspect worth noting has to do with the specific modality of exercise used in strength and endurance training. In the few studies that have used upper-body exercise modalities of resistance and endurance training there appeared to be no interference in strength development when concurrent training was compared with strength training alone (Leveritt et al. 1999), whereas the 'interference phenomenon' described by Hickson (1980) was relative to lower body exercise, in which muscle strength is not a limiting factor. It remains to be determined whether there exist differences in concurrent training when training upper or lower-body musculature.

In summary, a 12-wk periodized strength and endurance training programme with special emphasis on prioritizing the development of specific physical fitness components in each training phase (i.e. muscle hypertrophy and VT2 in P1, and maximal strength and aerobic power in P2) seems effective in improving both cardiovascular and neuromuscular markers of highly trained top-level athletes.

Acknowledgements

We thank personnel from the Andalusian High-Performance Sports Medicine Centre 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.

Conflict of interest

The authors declare that they have no conflict of interest relevant to the content of this manuscript.

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Manuscript II

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

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

Journal of Sports Science and Medicine 2009

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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% 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 testerone 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.

Keywords: 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 Déléris 2003), while less pronounced declines in VO_{2max} have been detected following shorter TC periods (Houmard et al. 1992; Houston et al. 1979). 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 cardiorrespiratory 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 (Mujika and Padilla 2000a; 2000b; Neufer et al. 1987). 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 ± 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 ± 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 ± 540 repetitions for hypertrophy; 44.4 ± 3.2 h, 42 ± 3 sessions, 642 ± 46 sets and 2,600 ± 199 repetitions for maximal strength; and 32.4 ± 1.1 h, 34 ± 2 sessions, 488 ± 29 sets and 2,673 ± 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 (~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 $km \cdot h^{-1}$, subjects completed an incremental paddling test to volitional exhaustion on a kayak ergometer (Dansprint ApS, Denmark; drag resistance coefficent = 35). The first stage was set at a speed of 11.5 $km \cdot h^{-1}$ and the speed increments were 0.5 $km \cdot h^{-1}$ 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 4ºC, and plasma stored at -80ºC 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 $mL \cdot kg^{-1} \cdot min^{-1}$; $P < 0.01$) and -5.6% (from 68.5 ± 3.0 to 64.6 ± 3.1 $mL \cdot kg^{-1} \cdot min^{-1}$; $P < 0.05$) 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%, $P < 0.05$) (Fig. 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 and Fig. 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 significantly higher ($P < 0.05$) for the RT compared to the TC group (Table 1).

Table 1. Changes in cardiorespiratory and kayaking performance variables.

	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 ± 0.5	14.6 ± 0.2*	15.2 ± 0.3	14.9 ± 0.3
PS_{VT2} (km·h^{-1})	14.1 ± 0.3	13.4 ± 0.3*	14.2 ± 0.3	13.6 ± 0.2*
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** †

Data are mean ± SD. TC: Training Cessation (n = 7); RT: Reduced Training (n = 7). Significant differences: * $P < 0.05$ compared to T1; ** $P < 0.01$ compared to T1; † $P < 0.05$ compared to TC.

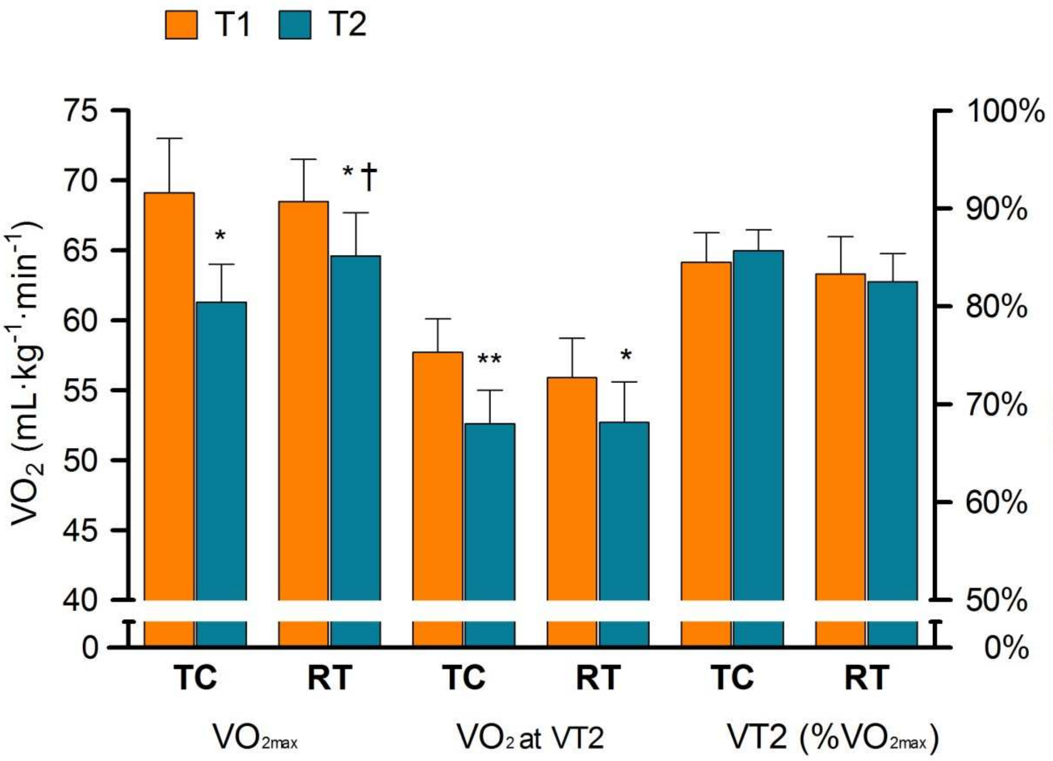

Fig. 1. Changes in VO_{2max}, VO_2 at VT2 and VT2(%VO_{2max}) following a 5-wk period of either training cessation (TC) or reduced training (RT). Significant differences: * $P < 0.05$ compared to T1; ** $P < 0.01$ compared to T1; † $P < 0.05$ compared to TC.

Resting hormones

From T1 to T2, similar decreases (-30%, $P < 0.01$) were detected in cortisol levels for the TC and RT groups. 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 ($P < 0.05$).

Table 2. Changes in resting hormones.

	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**†

Data are mean ± SD. TC = Training Cessation (n = 7); RT = Reduced Training (n = 7). Significant differences: ** P < 0.01 compared to T1; † P < 0.05 compared to TC.

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 Déléris 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 markedy 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. Additionaly, 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 VO_2 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 VO_2 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 VO_2 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 VO_2 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). 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; Mujika and Padilla 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 (Claude and Sharp 1991; Costill et al. 1985; Neufer 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 Déléris (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. Adittionally, Neufer 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 Hortobágyi 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 (Häkkinen 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 measurement 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 appropiate 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.

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.

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.

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JOURNAL OF SPORTS SCIENCE & MEDICINE
ELECTRONIC JOURNAL (ISSN 1303-2968)
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October 07, 2009

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Manuscript: #1344-2009/JSSM

TITLE: "POST-SEASON DETRAINING EFFECTS ON PHYSIOLOGICAL AND PERFORMANCE PARAMETERS IN TOP-LEVEL KAYAKERS: COMPARISON OF TWO RECOVERY STRATEGIES"

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Dear Jesús García-Pallarés ,

I am glad to inform you that your revised manuscript is accepted for publication in the Journal of Sports Science and Medicine and it will be published in December 2009 issue of JSSM. The manuscript will now be edited for style and format.

Please do not hesitate to contact me if you have any questions.

Thank you for giving the JSSM the opportunity to publish your work

Yours Sincerely

Hakan Gur, MD, PhD
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Manuscript III

“Physiological effects of tapering and detraining in world-class kayakers”.

Physiological effects of tapering and detraining in world-class kayakers

Medicine and Science in Sports and Exercise 2009

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Abstract

Purpose: This study analyzed changes in neuromuscular, body composition and endurance markers during 4-wk of tapering and subsequent 5-wk of reduced training (RT) or training cessation (TC). **Methods**: Fourteen world-class kayakers were randomly assigned to either a TC (n = 7) or RT group (n = 7). One-repetition maximum (1RM) strength, mean concentric velocity with 45% 1RM ($V_{45\%}$) in the bench press (BP) and prone bench pull (PBP) exercises, and body composition assessments were conducted at the start (T0) and end (T1) of a 43-wk training program, after tapering for the World Championships (T2) and following TC or RT (T3). A graded exercise test on a kayak-ergometer for determination of maximal oxygen uptake at T0, T1 and T3 was also performed. **Results**: Following tapering, no significant changes were observed in 1RM or $V_{45\%}$. TC resulted in significantly greater declines in 1RM strength (-8.9% and -7.8%, $P < 0.05$, respectively for BP and PBP) than those observed for RT (-3.9% and -3.4%). Decreases in $V_{45\%}$ in BP and PBP were larger for TC (-12.6% and -10.0%) than for RT (-9.0% and -6.7%). Increases in sum of eight skinfolds were observed after both TC and RT; whereas declines in maximal aerobic power were lower for RT (-5.6%) than for TC (-11.3%). **Conclusion**: Short-term training cessation results in large decreases in maximal strength and, especially, $V_{45\%}$ in highly-trained athletes. These results suggest the need of performing a minimal maintenance program to avoid excessive declines in neuromuscular function in cases where a prolonged break from training is required.

Key words: Training cessation; reduced training; maximal strength; muscle power; canoeing.

Introduction

A well-known and proven effective coaching strategy for improving sports performance before main competition events is to incorporate a tapering phase of significantly reduced training volume while the intensity is kept high (Gibala et al. 1994; Izquierdo et al. 2007; Mujika and Padilla 2000a; Mujika and Padilla, 2003; Mujika et al. 2004). It is believed that the taper enhances performance by allowing greater recovery (Gibala et al. 1994; Mujika and Padilla 2003; Mujika et al. 2004). Thus, it has been previously reported that after a period of tapering, moderately strength-trained subjects improved low velocity isokinetic strength performance of the elbow flexors for at least 8 days (Gibala et al. 1994). Izquierdo et al. (2007) found that 4-wk of tapering resulted in further increases for upper and lower body maximal strength and muscle power following periodized training in strength-trained athletes. Similarly, several studies that examined the effects of tapering in endurance athletes have attributed gains in performance to increased levels of muscular force and power (Hooper et al. 1998; Neary et al. 2003; Shepley et al. 1992; Trappe et al. 2000).

The incorporation of periods of 3-6 weeks of training cessation after the conclusion of the main event of the season in order to allow physical and mental recovery before the start of a new training cycle is a common training practice in many sports. In these situations, training reduction is generally preferred over complete exercise stoppage since it seems to be more effective to avoid the negative impact of insufficient training stimuli on athletic performance (Mujika and Padilla 2000b). The magnitude of performance declines observed after detraining periods appears to be related to the chosen recovery strategy (i.e. reduced training, RT; or complete training cessation, TC), initial fitness level, and total time under reduced or absence of training stimuli (Mujika and Padilla 2000a; 2000b; Mujika and Padilla 2001).

Current research seems to indicate that neuromuscular performance is more susceptible to decline as a consequence of detraining in highly-trained athletes compared to recently or moderately-trained individuals (Izquierdo et al. 2007; Mujika and Padilla 2001). Thus, in experienced, strength-trained athletes pronounced decreases in maximal dynamic strength in typical weight-training exercises such as bench press (9%), squat (10-12%) and leg-extension (12%) have been reported after 4-8 wk of TC (Häkkinen et al. 1981; Häkkinen et al. 1985; Izquierdo et al. 2007);

while in shorter periods of TC (2-wk) declines in muscle strength seem to be much lower (Hortobágyi et al. 1993) or nonexistent (Houmard et al. 1993). By contrast, in recently or recreationally-trained athletes, strength gains after short-term TC (4-6 wk) seem more readily retained (Houston et al. 1983; Kraemer et al. 2002; Terzis et al. 2008). In addition, muscle power seems to be lost at a greater rate than strength after detraining (Izquierdo et al. 2007; Kraemer et al. 2002; Neufer et al. 2007) especially among highly-trained athletes, although increased maximal rate of force development (Ishida et al. 1990) and phenotypic shift toward faster muscle characteristics (Andersen et al. 2005; Trappe et al. 2000) consequent to detraining have also been documented. To date, the majority of research that has studied the neuromuscular changes induced by tapering and detraining has used previously untrained or moderately-trained participants. However, little is known about the consequences that a taper, and short-term detraining period subsequent to a concurrent endurance and periodized heavy and explosive resistance training program, could have on neuromuscular performance markers in highly-trained strength and endurance athletes (e.g. Olympic kayakers).

Therefore, the aim of this study was to examine changes in selected parameters of muscle strength and velocity at maximum power loads, body composition and endurance performance brought about by a period of 5-wk of either RT or complete TC subsequent to an initial training program of 43-wk and a 4-wk tapering phase in a group of world-class kayakers.

Methods

Subjects

Fourteen male, elite flatwater kayak paddlers (including 10 finalists at World Championships, and 2 Olympic gold-medalists) volunteered to take part in this study. Characteristics of participants (mean ± 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 ± 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 was approved by the

Bioethics Commission of the University of Seville, and written informed consent was obtained from athletes prior to participation.

Study design

Subsequent to a full season (43-wk) of combined strength and endurance training, subjects completed a 4-wk tapering phase (TAP) in order to maximize performance in the Flatwater Racing World Championship, which had been established as their main objective of the season. A 5-wk detraining phase (DTR) immediately followed this event. During DTR subjects either fully discontinued any kind of physical training (TC group) or performed only one resistance training and two endurance training sessions per week (RT group). Athletes were matched for body mass, training experience and one-repetition maximum (1RM) strength in the bench press (BP) and prone bench pull (PBP) exercises and randomly assigned to either RT (N = 7) or TC (N = 7) groups. Participants reported to the laboratory on four separate occasions in order to assess the selected physiological and performance parameters (Fig. 1). 1RM strength, velocity at 45% 1RM load and body composition assessments were conducted right before the start of the season (wk-0; T0), at the beginning of TAP phase (wk-44; T1), the week corresponding to the World Championship (wk-47; T2), and finally after the DTR phase (wk-53; T3). A maximal graded exercise test on the kayak ergometer was conducted at T0, T1 and T3.

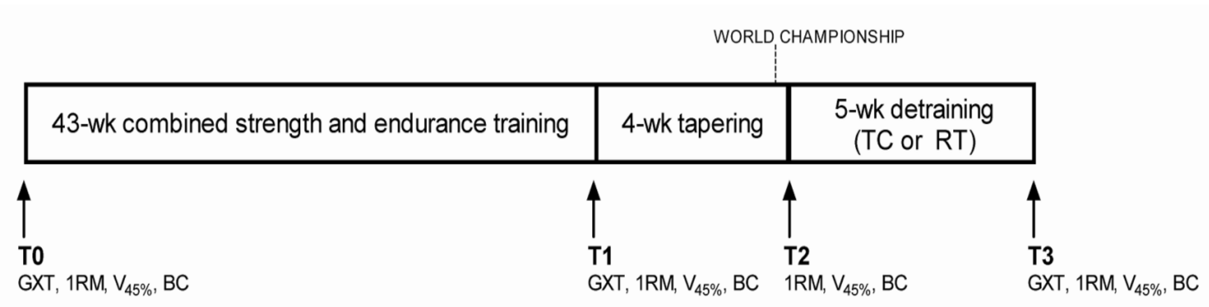

Fig. 1. Study design including calendar of testing. TC: Training Cessation; RT: Reduced Training; GXT: maximal graded exercise test; 1RM: one-repetition maximum strength test; $V_{45\%}$: velocity with 45% 1RM test; BC: body composition assessment.

Training intervention

From wk-1 to wk-43, paddlers undertook an exercise program of combined strength and endurance training, under the guidance and supervision of professional canoeing coaches. Strength training was structured into 4 periodized cycles of 10-12 wk, during which three types of strength training phases 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). Five main exercises were used: BP, PBP, shoulder press, pull-ups and squat. Training to repetition failure was deliberately avoided, and paddlers were constantly encouraged to perform each repetition at maximal concentric velocity. In maximal power training sessions each set was terminated when mean velocity decreased by more than 10% of the fastest repetition's mean concentric velocity. Total strength training volume during these 43-wk amounted to: 37.8 ± 2.6 h, 42 ± 3 sessions, 840 ± 60 sets and 7,560 ± 540 repetitions for hypertrophy; 41.8 ± 3.3 h, 38 ± 3 sessions, 608 ± 48 sets and 2,492 ± 197 repetitions for maximal strength; and 30.0 ± 1.1 h, 30 ± 2 sessions, 450 ± 30 sets and 2,475 ± 165 repetitions for maximal power. Endurance training was structured into 3 cycles of 11-22 wk duration. Actual endurance training volume was 249.8 ± 13.2 h at paddling speeds corresponding to 75-90% VO_{2max}, 35.7 ± 2.2 h between 90-105% VO_{2max}, and 7.1 ± 0.6 h above 105% VO_{2max} and required athletes to paddle 60-130 km (10-15 sessions) per week.

TAP consisted of 4-wk of progressively lowering training volume while increasing intensity. During this phase, subjects completed two strength training sessions per week: a) one maximum strength session with 90-95% 1RM (3-4RM) loads, 2-4 repetitions per set, and 2-3 sets per exercise; and b) one maximal power training session with 45% 1RM (BP, PBP) or 60% 1RM (squat) loads, 5-8 repetitions, and 3-4 sets. Exercises during TAP were limited to BP, PBP and squat. Total strength training volume was 2.6 ± 0.3 h, 34 ± 2 sets and 108 ± 4 repetitions for maximal strength; and 2.4 ± 0.2 h, 38 ± 5 sets and 198 ± 34 repetitions for maximal power. Furthermore, athletes performed 5-10 endurance paddling sessions per week, in which priority was given to high-intensity exercise while progressively reducing volume up to 50% of habitual training values. Actual time devoted to endurance training during TAP was 14.3 ± 0.6 h at paddling speeds corresponding to

75-90% VO_{2max}, 4.2 ± 0.1 h between 90-105% VO_{2max} and 1.5 ± 0.3 hours above 105% VO_{2max}, in addition to the three competition days at the end of this phase.

Lastly, during DTR, the TC group fully discontinued any kind of physical training during the following 5-wk, while the RT group performed only one resistance training and two endurance training sessions per week. During this period there was no control over the athletes' diet. The resistance training session performed by the RT group comprised 3 sets of 10 repetitions with each athlete's 70-75% 1RM (10-12RM) load in the BP, PBP and squat exercises, using 3-min pauses between sets. The endurance training consisted of only two 40-min moderate-intensity (~80% VO_{2max}) aerobic running and paddling sessions, respectively. On the four remaining weekdays no physical training of any kind was performed.

Testing

Testing was completed on three consecutive days: body composition and maximal graded exercise test on the kayak ergometer (day 1), 1 RM strength (day 2) and velocity at 45% 1RM assessment (day 3). The same warm-up procedures and protocol for each type of test were repeated on subsequent occasions. Testing was performed at the same time of the day (10-12 h) and under similar environmental conditions (20-22ºC and 55-65% humidity). The test-retest intraclass correlation coefficients for all variables measured in this study were greater than 0.93, with coefficients of variation ranging from 0.9% to 3.3%.

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 guidelines from the International Society for the Advancement of Kineanthropometry (2006). Body fat percentage and fat-free mass were estimated using Carter and Yuhasz' formula (1984).

Maximal graded exercise test

After a 5-min warm-up at a speed of 9 $km \cdot h^{-1}$, subjects completed an incremental paddling test to volitional exhaustion on a kayak ergometer (Dansprint ApS, Denmark). The first stage was set at a speed of 11.5 $km \cdot h^{-1}$ and the speed increment was 0.5 $km \cdot h^{-1}$ each minute. Each kayaker was allowed to freely adjust his stroke rate as needed. Paddlers were strongly encouraged to give maximal effort and to complete as many stages as possible. Breath-by-breath gas analysis was conducted throughout using an automated Jaeger Oxycon Pro system (Erich Jaeger, Germany) calibrated prior to each testing session. VO_{2max} was defined as the average of the single highest four consecutive 15-s VO_2 values attained towards the end of the test.

Maximal strength and velocity at maximum power loads assessments

Testing procedures can be found elsewhere (García-Pallarés et al. 2009). Briefly, 1RM was determined in the BP and PBP exercises using free weights. These were chosen because they are the most used resistance training exercises in the sport of canoeing and are useful to assess strength and power in the opposing upper-body muscle actions of pushing and pulling. The heaviest load that each athlete could properly lift in a purely concentric action was considered to be his 1RM. On the following day, mean velocity with 45% of 1RM load ($V_{45\%}$) was assessed for both exercises. This was chosen since it has been shown to be very close to the load that maximizes the average mechanical power output for upper-body resistance exercises (Baker et al. 2001; Cronin and Sleivert 2005). Paddlers performed 2 sets of 3 repetitions with 45% 1RM, using a 5-min pause between sets. Mean velocity was determined by means of a linear position transducer (MuscleLab, Ergotest Technology, Oslo, Norway). The mean velocity of the three best repetitions for each athlete was registered as $V_{45\%}$.

Statistical analysis

Standard statistical methods were used for the calculation of mean values and standard deviations (SD). A 2 x 4 factorial analysis of variance was performed in order to evaluate absolute changes in selected variables between time points (T0, T1, T2 and T3) and between groups (TC and RT). Effect sizes (ES) for changes in the TC and RT groups between T3 and T2 time points were calculated as the difference between the means divided by the average standard deviation for the two groups. Significance was accepted at the $P \leq 0.05$ level.

Results

No significant differences were observed at T0 between TC and RT groups in any of the following variables: body mass, fat-free mass, training experience, VO_{2max}, 1RM strength in BP and PBP, or $V_{45\%}$ in BP and PBP exercises.

Body Composition

Changes in body composition are reported in Table 1. Significant decreases ($P < 0.05$) were observed at T1 in sum of eight skinfolds for TC and RT groups. After TAP, a further but non-significant decrease in sum of eight skinfolds was observed in both TC (-4.9%) and RT (-5.3%) groups when comparing T2 and T1. At T3, no significant changes were observed in body mass in any group compared with T2; whereas significant increases ($P < 0.05$) were observed in sum of eight skinfolds for both TC (22.8%, ES = 3.12) and RT (23.2%, ES = 2.75). After DTR, no significant differences between groups were found in the magnitude of changes in sum of eight skinfolds; while significant group x time interaction was observed for fat-free mass, with a significantly larger ($P < 0.05$) magnitude of decrease for TC (-3%, $P < 0.05$) compared to RT (-0.1%, n.s).

Table 1. Time course of changes in body composition.

		T0	T1	Change T0-T1 (%)	T2	Change T1-T2 (%)	T3	Change T2-T3 (%)
TC	Body mass (kg)	85.6 ± 5.8	85.0 ± 5.4	-0.7	85.2 ± 5.8	0.2	85.0 ± 4.5	-0.2
	Fat-free mass (kg)	74.4 ± 2.7	75.9 ± 2.9	2.0	76.5 ± 2.9	0.8	74.2 ± 2.8#	-3.0
	Sum 8 skinfolds (mm)	72.3 ± 5.1	59.0 ± 4.4*	-18.4	56.1 ± 4.0	-4.9	68.9 ± 4.2#	22.8
RT	Body mass (kg)	86.7 ± 4.9	84.7 ± 5.5	-2.3	84.3 ± 4.8	-0.5	86.7 ± 4.6	2.8
	Fat-free mass (kg)	75.8 ± 2.9	76.0 ± 2.9	0.3	76.1 ± 2.7	0.2	76.2 ± 2.7†	0.1
	Sum 8 skinfolds (mm)	70.1 ± 4.5	56.8 ± 4.3*	-19.0	53.8 ± 4.5	-5.3	66.3 ± 4.6#	23.2

Data presented as mean ± SD. Skinfolds: triceps brachii, subscapular, suprailiac, abdominal, anterior thigh, medial calf, supraspinale and biceps brachii.
TC: Training Cessation group (N = 7); RT: Reduced Training group (N = 7); T0 = wk-0, start of the season; T1 = wk-44, beginning TAP phase; T2 = wk-47, World Championship week; T3 = wk-53, right after detraining.
Significant differences: * when comparing T1 to T0; # T3 to T2; † higher than TC at respective time point. P < 0.05.

Muscle strength

Significant increases (P < 0.05) in 1RM strength and $V_{45\%}$ were observed in BP and PBP exercises for both TC and RT groups, when comparing T1 with T0 (Fig. 2A). At T2, following TAP, no significant changes were observed in 1RM strength or $V_{45\%}$ values for any group. After DTR, significant group x time interaction was observed for 1RM strength, with a significantly larger (P < 0.05) magnitude of decrease for the TC group (-8.9% and -7.8%, P < 0.05, ES = -1.81 and -1.98, respectively for BP and PBP) than that observed for the RT group (-3.9% and -3.4%, n.s., ES = -0.67 and -0.87). Decreases in $V_{45\%}$ in BP and PBP exercises after DTR were larger for TC (-12.6% and -10.0%, ES = -2.15 and -1.67 respectively) than those observed for RT (-9.0% and -6.7%, ES = -1.67 and -0.67). No significant differences between groups were observed in the magnitude of changes in $V_{45\%}$ (Fig. 2B).

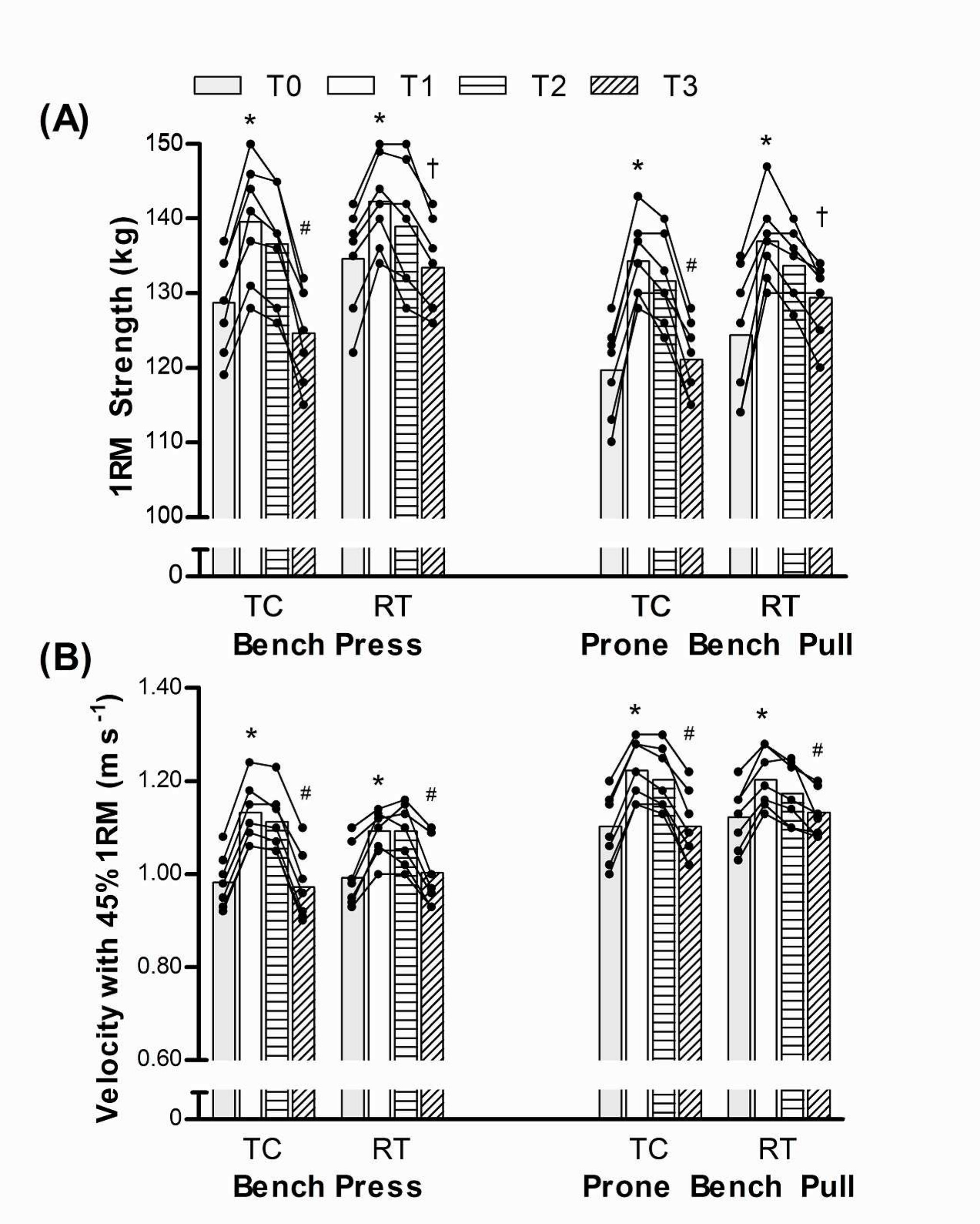

Fig. 2. Time course of changes in one-repetition maximum (1RM) strength (**A**), and velocity attained with 45% 1RM (**B**) in the bench press and prone bench pull exercises. TC: Training Cessation group (N = 7); RT: Reduced Training group (N = 7). Data presented as mean ± SD. Significant differences: * when comparing T1 to T0; # T3 to T2; † higher than TC at respective time point ($P < 0.05$).

Maximal aerobic power

At T1, significant increases ($P < 0.05$) in VO_{2max} were observed for both TC (8.8%, from 63.5 to 69.1 $mL \cdot kg^{-1} \cdot min^{-1}$) and RT (8.3%, from 63.2 to 68.5 $mL \cdot kg^{-1} \cdot min^{-1}$)

when comparing with T0. After DTR, significant group x time interaction was observed for VO_{2max} with a significantly larger (P < 0.05) magnitude of decrease for (-11.3%, from 69.1 to 61.3 $mL\cdot kg^{-1}\cdot min^{-1}$, P < 0.05, ES = -2.36) compared to RT (-5.6%, from 68.5 to 64.6 $mL\cdot kg^{-1}\cdot min^{-1}$, n.s., ES = -1.28). Time course of changes in VO_{2max} values, adjusted to account for fat-free mass, are shown in Fig. 3.

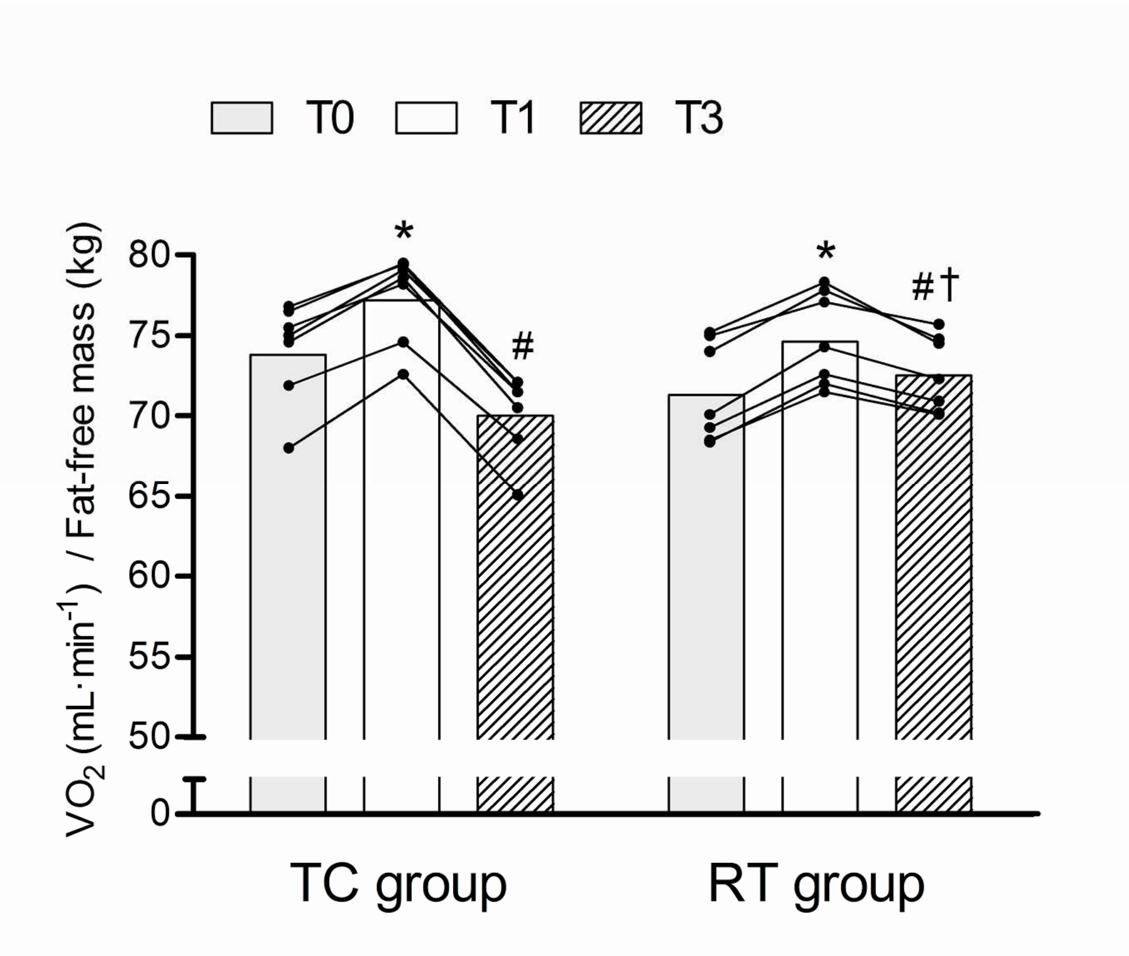

Fig. 3. Time course of changes in VO_{2max} values adjusted to account for fat-free mass. TC: Training Cessation group (N = 7); RT: Reduced Training group (N = 7). Data presented as mean ± SD. Significant differences: * when comparing T1 to T0; # T3 to T2; † higher than TC at respective time point (P < 0.05). Changes from T0 to T1, and T1 to T3 for both groups are reported in parentheses.

Discussion

This study examined the effects of a pre-competition taper (4-wk) and subsequent detraining period (5-wk) on neuromuscular, body composition and endurance performance changes in a group of world-class athletes whose sport (i.e. Olympic sprint kayaking) requires very high levels of both muscle strength and aerobic power. We have recently reported (García-Pallarés et al. 2009) that a periodized training program can be effectively used for simultaneously developing the different fitness components of strength and aerobic endurance in elite kayakers, yet there is a paucity of literature on the effects that typical tapering and/or short-term detraining periods could have on neuromuscular and performance markers for this type of top-level athletes. The main findings of the present study were that a period of 5-wk of markedly reduced training in a group of elite athletes seems effective for minimizing the large declines in strength levels that take place by completely stopping physical training for an equivalent period of time, as well as for maintaining fat-free mass close to habitual levels. However, velocity at 45% 1RM, although slightly better retained in the RT compared to the TC group, was more difficult to maintain when no specific training stimuli were provided. The 4-wk taper was effective for maintaining maximal strength and $V_{45\%}$, but not to further increase them. These data indicate that although both the RT and the TC groups decreased performance between T2 and T3, training cessation induces larger neuromuscular declines than those found after a reduced training strategy.

With the ever-increasing number of competitions and rigorous demands of modern sport at the elite level, experiencing an excessive loss of neuromuscular function during the layoff between seasons could have undesired detrimental consequences for the athletes' performance in subsequent training cycles. Furthermore, the reduced volume of training usually performed in the preceding precompetition tapering could add up to the aforementioned loss of physical conditioning. For top-level athletes, the present investigation has shown that significant strength is lost (8.9% and 7.8% declines in 1RM values for BP and PBP, respectively) after 5 wk of complete training cessation. By contrast, performing only one weekly resistance training session allowed the RT group to reduce by more than half the magnitude of maximal strength declines (3.9% for BP and 3.4% for PBP) (Fig. 2A). The non-significant loss of maximal strength after TAP (~2% for both groups and exercises) can likely be explained by the greatly reduced volume of strength-training during the full 4-wk duration of the taper by these already highly conditioned and muscular athletes. The 1RM strength decreases observed for the TC group following DTR were similar to those found by other authors in experienced, strength-trained athletes after 4-wk detraining: 10% for squat (Häkkinen and Komi 1993), 9% for BP and 6% for half-squat (Izquierdo et al. 2007). Longer periods of TC

(8-wk) seem to result in more pronounced declines in strength, as found by Häkkinen et al. (1981) who reported 11.6 and 12.0% decreases for squat and knee-extension exercises, respectively. However, after shorter periods of detraining, muscle strength declines were minimal (Hortobágyi et al. 1993; Houmard et al. 1993).

$V_{45\%}$ experienced significant reductions after the 5-wk of detraining, but remained unchanged after TAP. It seems therefore that the tapering period used in the present study was effective for maintaining velocity at maximal power loads levels but not to further increase their magnitude, a finding in agreement with that reported by Izquierdo et al. (2007) after a similar 4-wk taper. In the TC group, $V_{45\%}$ decreased by 12.6% and 8.3% in the BP and PBP exercises, respectively (Fig. 2B). Although somewhat lower, these declines were also notably significant (9.2% for BP and 6% for PBP) for $V_{45\%}$ in the RT group. The finding that detraining results in a larger reduction in muscle power than maximal strength has already been reported (Izquierdo et al. 2007; Kraemer and cols. 2002; Neufer et al. 1987) and suggests that very specific stimuli (i.e. 'power training') may be necessary to maintain maximal power levels in these highly-trained elite athletes. Thus, it can be further speculated that muscle power may be much more rapidly lost than maximal strength in elite athletes. These detraining-induced declines in neuromuscular performance detected in top-level athletes are similar to those described by Fry et al. (2006), who also found significant decreases in weight-trained athletes at the neuromuscular level after inducing overtraining. These data seem to emphasize the importance of establishing the optimal training load in each training phase when devising effective periodization schemes for highly trained athletes.

The increases in sum of eight skinfolds (~23%) observed after DTR for both groups are larger than those described in the literature for well-trained athletes after 2-6 wk of TC (Table 1) (Hortobágyi et al. 1993; Izquierdo et al. 2007; Terzis et al. 2008). These differences may be attributable to several factors: the lacking (TC) or insufficient (RT) aerobic endurance stimuli during the detraining period; the very low levels of fat registered for the kayakers at the major event of the season (T2); and the absence of control over the athletes' diet during DTR. The observed fat-free mass losses of 3% after TC are in line with results from previous studies (Allen 1989; Häkkinen et al. 1981) that detected decreased muscle mass after 6-8 wk of training stoppage. Unlike the TC group, fat-free mass remain unchanged in the RT group

(Table 1), thus supporting the use of some form of maintenance training during periods of detraining.

Of considerable interest was the fact that declines in VO_{2max} after DTR were much lower for the RT group (-5.6%), that performed only two maintenance endurance exercise sessions per week, than for the TC group (-11.3%) that completely discontinued endurance training for 5-wk. When expressing VO_{2max} values relative to fat-free mass (Fig. 3), the results similarly showed the effectiveness of the RT program. This finding may suggest the convenience of maintaining some reduced endurance stimuli during transition periods in an attempt to minimize losses in endurance performance.

In conclusion, our results support previous research showing that short-term training cessation results in larger decreases in muscle strength and power in resistance- and endurance-trained top-level athletes compared to a reduced training approach. Moreover, muscle power appears particularly susceptible to detraining in highly-conditioned athletes, being lost at a faster rate than maximal strength. These results may suggest the need of a minimal maintenance program of reduced training to avoid excessive declines in neuromuscular function and fat-free mass in cases where a prolonged break (longer than 2-3 wk) from training is required.

Acknowledgements

We thank personnel from the High-Performance and Sport Science Research Center (CARICD) in Madrid for their excellent technical help with laboratory apparatus and medical assistance to the athletes. No funding was received for this work from any institution. The results of the present study do not constitute endorsement by ACSM.

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Congratulations to you and coauthors (Jesús García-Pallarés, Luis Sánchez-Medina, Carlos E. Pérez, Mikel Izquierdo-Gabarren, Mikel Izquierdo) on the acceptance of your manuscript, "Physiological effects of tapering and detraining in world-class kayakers" .Your manuscript will be published in the June 2010 *Medicine & Science in Sports & Exercise*.

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ANEXO 2

PUBLICACIONES TRADUCIDAS AL CASTELLANO I-III

Artículo I

“Cambios neuromusculares y de resistencia en kayakistas de elite mundial durante un ciclo de entrenamiento periodizado”

Cambios neuromusculares y de resistencia en kayakistas de elite mundial durante un ciclo de entrenamiento periodizado

European Journal of Applied Physiology 2009

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Resumen

Este estudio se llevó a cabo para analizar los cambios en las variables cardiorrespiratorias y neuromusculares de un grupo de kayakistas de élite durante un ciclo periodizado con entrenamiento concurrente de fuerza y resistencia. Once kayakistas de elite mundial se sometieron a una batería de test en cuatro ocasiones durante el ciclo de entrenamiento (T0, T1, T2 y T3). En cada ocasión lo sujetos completaron un test incremental maximal hasta el agotamiento en kayak ergómetro para determinar el consumo máximo de oxígeno (VO_{2max}), el segundo umbral ventilatorio (VO_2VT2), ácido láctico pico en sangre, velocidad de paleo en VO_{2max} (V_{max}), velocidad de paleo en VT2 (V_{VT2}), frecuencia de paleo en VO_{2max} y en VT2, así como la frecuencia cardiaca en VO_{2max} y en VT2. Se realizaron test de una repetición máxima (1RM) y de velocidad media de desplazamiento ante el 45% del 1RM ($V_{45\%}$) en los ejercicios de Press Banca (PB) y Dorsal Remo (DR). También se establecieron las mediadas antropométricas (pliegues cutáneos y perímetros musculares). El volumen y la intensidad de entrenamiento fueron cuantificados para cada una de las tres fases de entrenamiento (F1, F2 and F3). Se observaron aumentos significativos en el VO_{2max} (9.5%), VO_2VT2 (9.4%), V_{max} (6.2%), V_{VT2} (4.4%), 1RM en PB (4.2%) y en DR (5.3%), $V_{45\%}$ en PB (14.4%) y en DR (10.0%) al comparar T3 con T0. En resumen, doce semanas de entrenamiento concurrente de fuerza y resistencia, con especial atención para priorizar el desarrollo secuencial de unos componentes específicos del rendimiento físico en cada una de las fases (es decir, hipertrofia muscular y VT2 en la F1; fuerza máxima y potencia aeróbica en la F2), parece ser efectivo para la mejora del rendimiento deportivo, tanto a nivel cardiorrespiratorio como neuromuscular, en palistas de alto nivel.

Palabras clave: Entrenamiento concurrente, entrenamiento de fuerza, entrenamiento de resistencia, rendimiento aeróbico, piragüismo, valoración, periodización.

Introducción

Generalmente es aceptado por los entrenadores y científicos del deporte que para maximizar las adaptaciones fisiológicas y para evitar el sobreentrenamiento es necesario un adecuado manejo de las diferentes variables que definen el programa de entrenamiento (principalmente intensidad, frecuencia y volumen de entrenamiento). Esto se hace especialmente importante en aquellos deportes donde es necesario el desarrollo simultáneo de fuerza y resistencia para optimizar el rendimiento deportivo (por ejemplo en la especialidad del piragüismo). Debido a que el entrenamiento de fuerza y resistencia producen distintos, e incluso a menudo opuestos, mecanismos adaptativos (Nader 2006; Sale y cols. 1990a), el desarrollo combinado de ambos componentes en el mismo régimen de entrenamiento puede desencadenar en un conflicto de adaptaciones neuromusculares.

Este conflicto potencial se ha denominado “fenómeno de interferencia” y fue descrito en un primer momento por Hickson (1980), quién observó conflictos en las adaptaciones de la fuerza cuando la resistencia y la fuerza se desarrollaban de forma combinada. Sin embargo, los resultados de investigaciones posteriores han sido dispares, con estudios cuyos resultados concuerdan con las aportaciones de Hickson (Bell y cols. 2000; Craig y cols. 1991; Dudley y Djamil 1985; Hennessy y Watson 1994; Kraemer y cols. 1995) y otros que cuestionan la naturaleza de esas interferencias (Häkkinen y cols. 2003; Hunter y cols. 1987; McCarthy y cols. 1995, 2002; Sale y cols. 1990a). Diversos factores como el nivel inicial de rendimiento, tipos de ejercicios, volumen, intensidad y frecuencia de entrenamiento, distribución de las sesiones y la selección de las variables dependientes pueden influir en el nivel de interferencia y por lo tanto explicar los resultados contradictorios de estos estudios (Docherty y Sporer 2000; Leveritt y cols. 1999; Sale y cols. 1990a). Un examen detallado de las investigaciones existentes sobre esta temática, parecen indicar que el volumen, y en especial la frecuencia de entrenamiento, puede jugar un papel vital en la adaptaciones con el entrenamiento concurrente (Häkkinen y cols. 2003; Izquierdo y cols. 2005; McCarthy y cols. 2002).

Por ejemplo, la mayoría de los estudios determinaron que el entrenamiento concurrente únicamente perjudicó las mejoras de fuerza cuando la frecuencia de entrenamiento era mayor de 3 días a la semana (Dudley y Djamil 1985; Hennessy y

Watson 1994; Hickson 1980; Hunter y cols. 1987; Kraemer y cols. 1995). Los mecanismos neuromusculares relacionados con el desarrollo de potencia y fuerza explosiva parecen verse más afectados por el entrenamiento simultaneo de fuerza y resistencia (Dudley y Djamil 1985; Häkkinen y cols. 2003; Hennessy y Watson 1994; Kraemer y cols. 1995). Sin embargo, la mayoría de las investigaciones de entrenamiento concurrente apoyan la idea de que el entrenamiento simultáneo de fuerza y resistencia no altera la capacidad del organismo de adquirir adaptaciones de resistencia (Docherty y Sporer 2000; Hickson y cols. 1988). Por otro lado, diferentes estudios han concluido que la inclusión del entrenamiento de fuerza en la preparación de atletas de resistencia bien entrenados tiene resultados beneficiosos para el rendimiento de resistencia (Hickson y cols. 1988; Mikkola y cols. 2007; Millet y cols. 2002). No obstante, la cuestión de cuál es la mejor secuencia para las sesiones de entrenamiento sobre diferentes objetivos en el desarrollo simultáneo de fuerza y resistencia, sigue siendo complejo y no se ha resuelto satisfactoriamente.

Existen algunas evidencias que apoyan que los programas de fuerza periodizados pueden producir mayores ganancias de fuerza que los no periodizados (Fleck 1999; Willoughby 1993). Los modelos no lineales u ondulatorios, en los que cortos periodos de tiempo con alto volumen de entrenamiento son alternados con cortos periodos de alta intensidad de entrenamiento, han sido diseñados para optimizar las ganancias de fuerza (Baker y cols. 1994). Desafortunadamente, existe muy pocos estudios en la literatura científica que exploren los efectos del entrenamiento periodizado en deportes con altas demandas de fuerza y resistencia, y menos aún que hayan empleado atletas de élite como sujetos experimentales. En base a los hallazgos de investigaciones previas (Docherty y Sporer 2000; Leveritt y cols. 1999, 2000; Sale y cols. 1990b; Sporer y Wenger 2003) se escogió para esta investigación una estructura de entrenamiento periodizado con objeto de minimizar las posibles interferencias en el entrenamiento simultáneo de fuerza y resistencia. Por lo tanto, la propuesta de este estudio fue analizar los efectos que produjeron 12 semanas de un programa periodizado con entrenamiento concurrente de fuerza y resistencia sobre los parámetros cardiorrespiratorios y neuromusculares, en un grupo de kayakistas de elite mundial.

Método

Muestra

Once hombres palistas de elite mundial (todos ellos finalistas de Campeonatos del Mundo, incluidos dos campeones olímpicos) tomaron parte de forma voluntaria en este estudio. La media (DE) de las características de los participantes fue la siguiente: edad 26.2 (2.8) años; altura 1.83 (0.07) m; masa corporal 86.2 (5.2) kg; experiencia en el entrenamiento12.4 (2.1) años; volumen de paleo anual 4220 (354) km. Todos los sujetos tenían al menos 3 años de familiarización con los procedimientos de valoración empleados en la investigación, y todos ellos siguieron sus respectivas rutinas de entrenamiento bajo la estricta supervisión de entrenadores y científicos del deporte de la Real Federación Española de Piragüismo.

No se detectaron limitaciones físicas o lesiones musculoesqueléticas que pudieran afectar el entrenamiento. Los kayakistas se sometieron a un examen médico completo (incluido electrocardiograma) que mostró que todos estaban en buen estado de salud. Esta investigación, que se llevó a cabo bajo las directrices de la declaración del Helsinki, fue aprobada por el Comité de Bioética de la Universidad de Sevilla, y se obtuvo un consentimiento informado de todos los sujetos participantes antes de comenzar la investigación.

Entrenamiento previo

Antes de comenzar la fase experimental, todos los participantes completaron una fase de transición de 5 semanas durante la cual no realizaron ningún tipo de entrenamiento de paleo o entrenamiento de fuerza y únicamente realizaron alguna actividad recreativa a baja intensidad.

Diseño experimental y secuencia de valoraciones

Todos los participantes siguieron el mismo programa durante las 12 semanas del estudio. Los palistas fueron convocados en el laboratorio en cuatro ocasiones diferentes (T0, T1, T2 y T3) a lo largo de la intervención con objeto de evaluar las variables cardiovasculares, neuromusculares y antropométricas seleccionadas. Las valoraciones se llevaron a cabo en tres días consecutivos: antropometría y test incremental maximal en kayak ergómetro (día 1), una repetición máxima (1RM) (día 2) y test de potencia (día 3). Los palistas no realizaron esfuerzos extenuantes las 24 horas previas a la realización de los test. Se repitieron los mismos procedimientos de calentamiento y protocolos en todas las valoraciones, y todos los test se realizaron a la misma hora del día (10-12h) y bajo similares condiciones ambientales (20-22 ºC y 55-65% de humedad). En un estudio piloto, la fiabilidad inter-test para la medición del VO_{2max}, VO_2VT2, y la frecuencia cardiaca a nivel del VO_{2max} se evaluó realizando dos test incrementales a 12 kayakistas junior de nivel internacional en kayak ergómetro con una separación de 3 semanas. No se encontraron diferencias significativas en las medidas estudiadas durante estas 3 semanas. El coeficiente de variación para el VO_{2max}, VT2 y la FC_{max} se mantuvieron entre 3.2 y 5.1%. El coeficiente de correlación interclase para todas las variables de fuerza/potencia analizadas en este estudio fueron mayores de 0.93 y el coeficiente de variación osciló entre 0.9 y 2.9%.

Para el diseño de esta investigación no se propuso un grupo control ya que no podría considerarse ético. La retención de estímulos importantes de entrenamiento podría ser perjudicial para el progreso deportivo del atleta (Kraemer 2005).

Antropometría

Las medidas antropométricas practicadas fueron: talla, masa corporal, pliegues cutáneos (tríceps, subescapular, suprailiaco, abdominal, muslo anterior, pierna medial, supraespinal y bíceps braquial), y diámetros musculares (torácico, antebrazo, muslo y pierna), y fueron medidos por el mismo investigador experimentado de acuerdo a las directrices de la International Society for the Advancement of Kineanthropometry (ISAK). La talla se midió con una precisión de 0.1 cm, durante una inhalación máxima, y la masa corporal se estableció con una precisión de 0.1 kg empleando una báscula calibrada (Seca 714, Hamburg, Germany); los pliegues cutáneos y los perímetros musculares se midieron, respectivamente, con un plicómetro (precisión de 0.2 mm) y una cita métrica inextensible (1 mm) (Holtain Ltd., UK).

Test incremental maximal

Tras 5 minutos de calentamiento a una velocidad de 9 km·h^{-1}, los sujetos completaron un test incremental de paleo hasta el agotamiento en un kayak ergómetro (Dansprint ApS, Denmark). El primer escalón del test se completó a 11.5 km·h^{-1}, y la velocidad se incrementó 0.5 km·h^{-1} cada minuto. Cada sujeto adaptó libremente la frecuencia de paleo (FP) a sus necesidades, y se registró continuamente su evolución durante el test con un frecuenciómetro (Interval 2000, Nielsen-Kellerman, USA). La frecuencia cardiaca (FC) se monitorizó empleando un pulsómetro telemétrico estándar (S610i; Polar Electro Oy, Finland) y se tomaron registros cada 5 segundos. Se alentó a los palistas a realizar el máximo esfuerzo voluntario y completar el mayor número posible de escalones del test. La prueba se dio por concluida cuando: a) el sujeto detuvo el paleo voluntariamente por extenuación, o b) por incapacidad de mantener la velocidad requerida. Se realizó un análisis de gases respiración a respiración empleando para ello un analizador de gases Jaeger Oxycon Pro system (Erich Jaeger, Germany). Se calibró el analizador de gases usando una mezcla de gases 4.95% CO_2-95.05% N_2 (BOC Gases, Surrey, UK), y el sensor de volumen usando una jeringa de calibración 3-L. Se determinó el segundo umbral ventilatorio (VT2) empleando el método V-slope ($VCO_2 \cdot VO_2$), así como a través del método de los equivalentes ventilatorios ($V_E \cdot VO_2^{-1}$ y $V_E \cdot VCO_2^{-1}$) y la presión del O_2 y CO_2 al final de la fase espiratoria ($PETO_2$ y $PETCO_2$). Dos observadores independientes realizaron las determinaciones del VT2. En caso de discrepancia, un tercer observador realizó la determinación. El VO_{2max} se definió como la media de los cuatro valores consecutivos más elevados de VO_2 hacia el final de la prueba. Se determinaron las siguientes variables para cada palista: FC en VO_{2max} (FC_{max}), FC en VT2 (FC_{VT2}), FP en VO_{2max} (FP_{max}), FP en VT2 (FP_{VT2}), velocidad de paleo en VT2 (V_{VT2}) y velocidad aeróbica máxima (V_{max}), definida como la velocidad del último escalón completado durante el test incremental. Se tomaron muestras de sangre capilar para cada palista en el lóbulo de la oreja durante la recuperación del test (minutos 1, 3, 5, 7, 10 y 12) para determinar la concentración pico de ácido láctico ($[La^-]_{pico}$), empleando para ello un analizador de lactato (LF20; Dr. Lange, France).

Valoración de la fuerza dinámica máxima y la potencia muscular

Se estableció el 1RM en Press Banca (PB) y en dorsal remo (DR) con peso libre. Ambos ejercicios fueron escogidos porque son los ejercicios típicos de entrenamiento de fuerza en piragüismo, y son dos ejercicios útiles para valorar la fuerza y potencia en las acciones musculares de empuje y tracción del tren superior. El calentamiento consistió en 5 minutos de pedaleo en bicicleta estática a baja intensidad, a continuación realizaron 5 minutos de estiramientos y ejercicios de movilidad articular del tren superior. Tras 3 minutos de recuperación, realizaron en cada ejercicio (PB y DR) una serie de 6 repeticiones con una carga del 60% del 1RM estimado, y otra serie de 2-3 repeticiones con la carga del 80% del 1RM estimado. A partir de ese momento, cada sujeto realizó 3-5 intentos de una repetición máxima con 5 minutos de pausa entre repeticiones hasta que su 1RM pudo ser establecido con una precisión de 2.5 kg. Tras dos intentos fallidos ante una misma carga el test se dio por concluido. La carga más pesada que cada sujeto pudo levantar, sin ningún tipo de ayuda externa, fue considerada su 1RM.

El día siguiente (día 2) se evaluó en ambos ejercicios la velocidad media de la fase concéntrica con el 45% del 1RM establecido previamente ($V_{45\%}$). Esta carga coincide con la resistencia que maximiza la potencia mecánica media para ejercicios del tren superior (Cronin y Sleivert 2005; Izquierdo y cols. 2002). Tras realizar el mismo calentamiento, los palistas realizaron dos series de tres repeticiones con la carga del 45% del 1RM, recuperando 5 minutos entre series. La velocidad media de la fase concéntrica fue medida por un trasductor lineal de posición (MuscleLab, Ergotest Technology, Oslo, Norway). La $V_{45\%}$ se definió como la velocidad media de las tres mejores repeticiones de cada sujeto. En el ejercicio de press banca los sujetos se tumbaron en posición decúbito supino en un banco plano, con los pies en el suelo y con las manos agarrando la barra con una separación ligeramente superior a la anchura e hombros (5-7 cm). Tras descender la barra hasta el pecho, el sujeto empujó la barra a la máxima velocidad voluntaria hasta la extensión completa de los codos. No se permitió rebotar la barra en el pecho o levantar los hombros o el tronco del banco. En el ejercicio de dorsal remo los palistas se tumbaron en posición decúbito prono en un banco plano elevado. La fase de tracción comenzó con ambos codos en completa extensión, con una separación entre en el agarre de manos sobre la barra ligeramente superior a la anchura de hombros (4-5 cm). Los sujetos fueron instruidos en traccionar de la barra a la máxima velocidad voluntaria, hasta que la barra impactase en el banco a la altura de su pecho, tras lo cual la barra descendía lentamente hasta la posición de partida.

Programa de entrenamiento periodizado

El ciclo de entrenamiento se dividió en tres fases de entrenamiento consecutivas. Las fases uno (F1: desde T0 a T1) y dos (F2: desde T1 a T2) tuvieron una duración de cinco semanas, mientras que la fase final (F3: desde T2 a T3) tuvo una duración de dos semanas. Se escogió un objetivo de entrenamiento de fuerza y otro de resistencia para priorizar sobre ellos el trabajo en cada fase: F1, VT2 e hipertrofia muscular; F2, potencia aeróbica y fuerza máxima; y F3, puesta a punto, distribución del esfuerzo y ritmo de competición. Los test se realizaron en la primera semana de cada fase (T0, T1 y T2) y de nuevo en la semana 13, tras concluir el programa de entrenamiento (T3). Los palistas entrenaron diariamente, a excepción de un día de descanso completo a la semana. Las sesiones de entrenamiento de fuerza se dispusieron preferentemente con anterioridad a las sesiones de resistencia; cuando esto no fue posible, se estableció suficiente tiempo de recuperación (6-8 h) antes de comenzar la sesiones de entrenamiento de fuerza. La implicación de todos los deportistas con los requerimientos del entrenamiento fue excelente.

Entrenamiento de resistencia

Se identificaron tres zonas de entrenamiento de acuerdo con la intensidad del esfuerzo: zona 1 (Z1), baja intensidad, por debajo del VT2: zona 2 (Z2), intensidad moderada, entre VT2 y el 90% del VO_{2max}; y la zona 3 (Z3), alta intensidad, entre el 90% del VO_{2max} y el 100% del VO_{2max}. No se realizó a lo largo del estudio ningún estímulo de entrenamiento de intensidad superior al VO_{2max}. En la Tabla 1 se muestra las características de los métodos de entrenamiento de resistencia para cada una de las zonas de intensidad. La contribución relativa de cada zona de entrenamiento al volumen total fue marcadamente diferente (Fig. 1). El volumen y la intensidad de entrenamiento se cuantificaron cuidadosamente para cada sesión de entrenamiento durante las 12 semanas que duró el ciclo de entrenamiento. Las principales variables empleadas para monitorizar el entrenamiento de resistencia fueron; tiempo empleado (horas) y distancia cubierta (km) para el volumen; y frecuencia cardiaca y velocidad de paleo para la intensidad. La distancia y la velocidad se registraron por medio de un receptor de GPS (Garmin 201, Garmin Ltd., USA). El tiempo total dedicado al entrenamiento de resistencia fue de 52.7 ± 1.9 h en F1, 49.5 ± 1.5 h en F2 y 21.5 ± 0.8 h en F3. Se realizaron entre 10-15 sesiones de entrenamiento de resistencia semanales.

Tabla 1. Descripción de los métodos de entrenamiento de la resistencia empelados para cada zona de intensidad.

Zona de Intensidad	Volumen de entrenamiento (min)	Series	Repeticiones	Tiempo de trabajo (min)	Recuperación (min)	Intensidad (%VO_{2max})
Z1	70 - 120	1	1-3	20 - 90	1 - 3	70%-80%
Z2	40 - 90	1 - 4	1-10	5 - 20	1 - 4	80%-90%
Z3	20 - 60	2 - 5	4-8	1 - 8	2 - 8	90%-100%

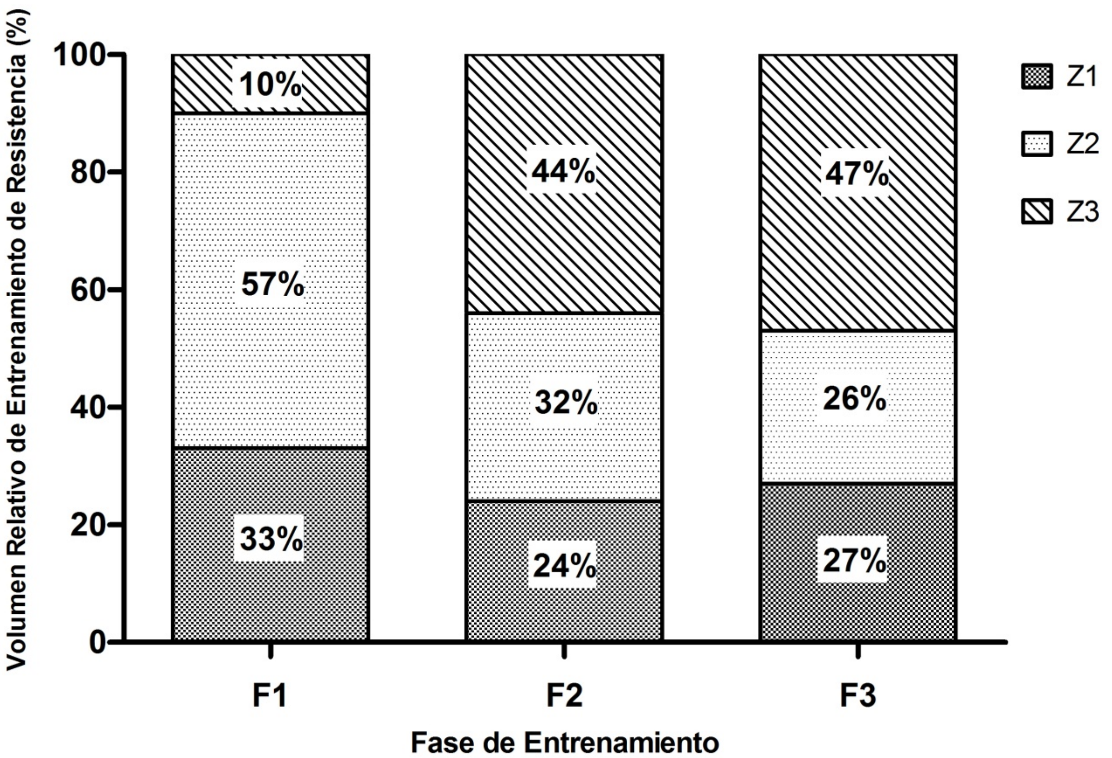

Fig. 1. Contribución relativa de cada zona de intensidad al volumen total de entrenamiento completado en cada fase. Z1: baja intensidad, por debajo del VT2; Z2: intensidad moderada, entre el VT2 y el 90% del VO_{2max}; Z3: alta intensidad, entre el 90% y el 100% del VO_{2max}.

Entrenamiento de fuerza

El tipo de ejercicios, el porcentaje de 1RM, el número de series y repeticiones, así como los tiempos de recuperación entre series fueron diferentes en cada una de las fases de entrenamiento (Tabla 2). Los palistas realizaron tres sesiones de entrenamiento de fuerza semanales durante todo el ciclo. Se evitó alcanzar la repetición del fallo en todas las series de entrenamiento de hipertrofia y fuerza máxima, y se motivó constantemente a los palistas para que realizasen la fase concéntrica de cada repetición a la máxima velocidad voluntaria, sin atender a la carga que estaba siendo levantada. La fase excéntrica siempre se realizó de forma controlada y lenta. En las sesiones de entrenamiento de potencia máxima, cada serie se dio por concluida cuando la velocidad media descendía por debajo del 10% de la mejor repetición (la repetición con la fase concéntrica más rápida). En todas las sesiones de entrenamiento de fuerza se registró el volumen usando la carga total levantada (kg) y el número de repeticiones completadas. La intensidad se evaluó como el porcentaje de 1RM, y como la velocidad media de la fase concéntrica medida por el trasductor lineal de posición. Todas las sesiones de entrenamiento fueron supervisadas por entrenadores profesionales con varios años de experiencia en el entrenamiento de piragüistas. El volumen total de entrenamiento de fuerza fue 15.6 ± 0.8 h y 2,430 ± 42 repeticiones durante F1, 13.2 ± 0.7 h y 660 ± 13 durante F2, y 8.4 ± 0.5 h y 520 ± 14 repeticiones durante F3. La contribución relativa de cada tipo de entrenamiento al volumen total de cada fase se muestra en la Fig. 2.

Tabla 2. Tipos y características de los entrenamientos de fuerza.

	Ejercicios	Series	Repeticiones	Carga (%1RM)	Recuperación
Hipertrofia	Press Banca, Dorsal Remo, Sentadilla, Press de Hombros, Dominadas	4 - 5	8 - 10	70%-75%	2 min
Fuerza Máxima	Press Banca, Dorsal Remo, Sentadilla	3 - 4	3 - 4	85%-90%	4 min
Potencia Máxima	Press Banca, Dorsal Remo	4 - 5	5 - 8*	45%	4 min

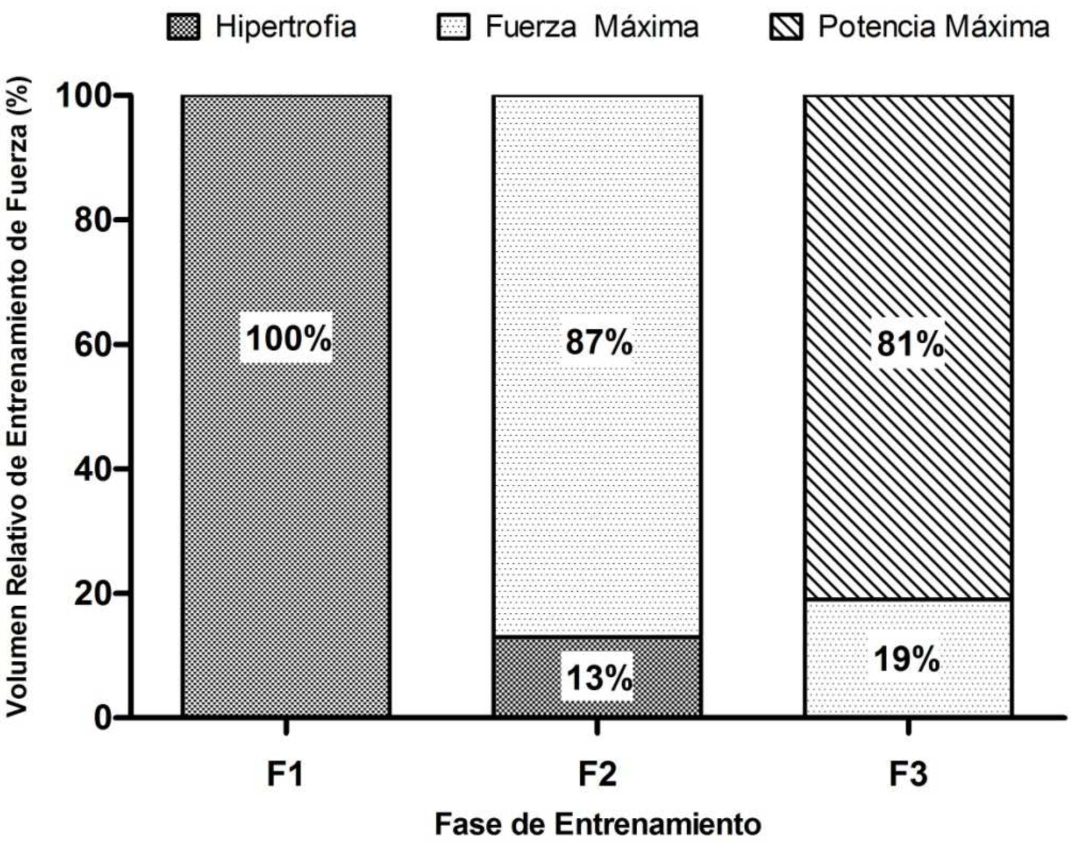

Fig. 2. Contribución relativa de cada tipo de entrenamiento de fuerza al volumen total de entrenamiento en cada fase.

Análisis Estadístico

Se emplearon métodos estadísticos estándar para el cálculo de los valores medios y de las desviaciones estándar (DE). Se aplicó el test de Kolmogorov–Smirnov para determinar la naturaleza de la distribución de los datos. Una vez confirmada una distribución normal se empleó una ANOVA de medidas repetidas para evaluar los cambios en las variables estudiadas a lo largo de las 12 semanas del periodo de entrenamiento (T0-T1-T2-T3). Se llevó a cabo el test Tukey post hoc para identificar la fuente de cualquier diferencia significativa. En todo caso, se consideró un nivel de confianza de $P \leq 0.05$.

Resultados

Cambios Antropométricos

Los cambios en las medidas antropométricas se muestran en la Tabla 3.

Tabla 3. Cambios en las variables antropométricas durante las 12 semanas del programa de entrenamiento.

	T0	T1	T2	T3
Masa Corporal (kg)	86.0 ± 4.4	88.1 ± 4.8	85.9 ± 4.5	85.6 ± 4.6
Sumatorio de 4 pliegues (mm)	35.5 ± 2.9	34.0 ± 2.3	29.0 ± 2.1[#]	34.3 ± 2.3[£]
Sumatorio de 8 pliegues(mm)	67.4 ± 5.1	63.5 ± 4.3	53.5 ± 3.9[#]	63.8 ± 4.5[£]
Perímetro del muslo (cm)	56.4 ± 1.8	58.2 ± 1.6	57.6 ± 1.6	57.3 ± 1.8
Perímetro torácico (cm)	105.2 ± 3.8	109.2* ± 3.9	107.5 ± 3.4	107.1 ± 3.9
Perímetro del antebrazo (cm)	28.6 ± 1.1	29.3 ± 1.1	28.9 ± 1.3	28.7 ± 1.1
Perímetro de la pierna (cm)	36.0 ± 0.7	37.2 ± 0.9	37.0 ± 1.0	37.0 ± 0.9

Los datos se presentan como media ± DE
* Diferencia significativa (P < 0.05) al comparar T0 y T1
[#] Diferencia significativa (P < 0.05) al comparar T1 y T2
[£] Diferencia significativa (P < 0.05) al comparar T2 y T3
[a]4 Pliegues: tríceps, subescapular, supraespinal, abdominal
[b]8 Pliegues: 4 pliegues + bíceps, suprailiaco, muslo anterior, pierna medial

Cambios en las variables cardiorrespiratorias y de resistencia

El VO_{2max} aumentó un 3.5% de T0 a T1 (P = 0.063) y un 5.3% de T1 a T2 (P < 0.05), mientras que no se detectaron diferencias significativas en el VO_{2max} entre T2 y T3. El VO_2VT2 aumentó significativamente entre T0 y T1 (12.4%, P < 0.05) pero descendió significativamente entre T1 y T2 (-4.3%). El VT2(%VO_{2max}) aumentó significativamente de T0 a T1 (8.6%, P < 0.01), mientras que descendió un -9% (P < 0.01) al comparar T1 y T2. La V_{max} mejoró en T1 (2.1%, P < 0.05), T2 (2.0%, P = 0.068) y T3 (2.0%, P < 0.05). No se detectaron cambios significativos para el resto de variables analizadas (FC_{max}, FC_{VT2}, FP_{max}, FP_{VT2}, y $[La^-]_{pico}$) (Tabla 4; Fig. 3).

Tabla 4. Cambios en las variables cardiovasculares y de resistencia durante las 12 semanas del programa de entrenamiento.

	T0	T1	T2	T3
V_{max} ($km \cdot h^{-1}$)	14.5 ± 0.3	14.8 ± 0.2*	15.1 ± 0.3	15.4 ± 0.2£ †
V_{VT2} ($km \cdot h^{-1}$)	13.6 ± 0.2	13.9 ± 0.2*	14.1 ± 0.2	14.2 ± 0.3†
$[La^-]_{pico}$ ($mmol \cdot L^{-1}$)	12.5 ± 3.3	11.8 ± 2.5	12.8 ± 2.2	13.0 ± 2.8
FC_{max} ($latidos \cdot min^{-1}$)	194 ± 8	188 ± 8	189 ± 10	189 ± 7
FC_{VT2} ($latidos \cdot min^{-1}$)	175 ± 7	172 ± 7	171 ± 6	172 ± 6
FP_{max} ($paladas \cdot min^{-1}$)	104 ± 5	101 ± 9	101 ± 7	103 ± 8
FP_{VT2} ($paladas \cdot min^{-1}$)	88 ± 4	84 ± 6	85 ± 5	85 ± 7

Los datos se presentan como media ± DE
* Diferencia significativa ($P < 0.05$) al comparar T0 y T1
£ Diferencia significativa ($P < 0.05$) al comparar T2 y T3
† Diferencia significativa ($P < 0.05$) al comparar T0 y T3

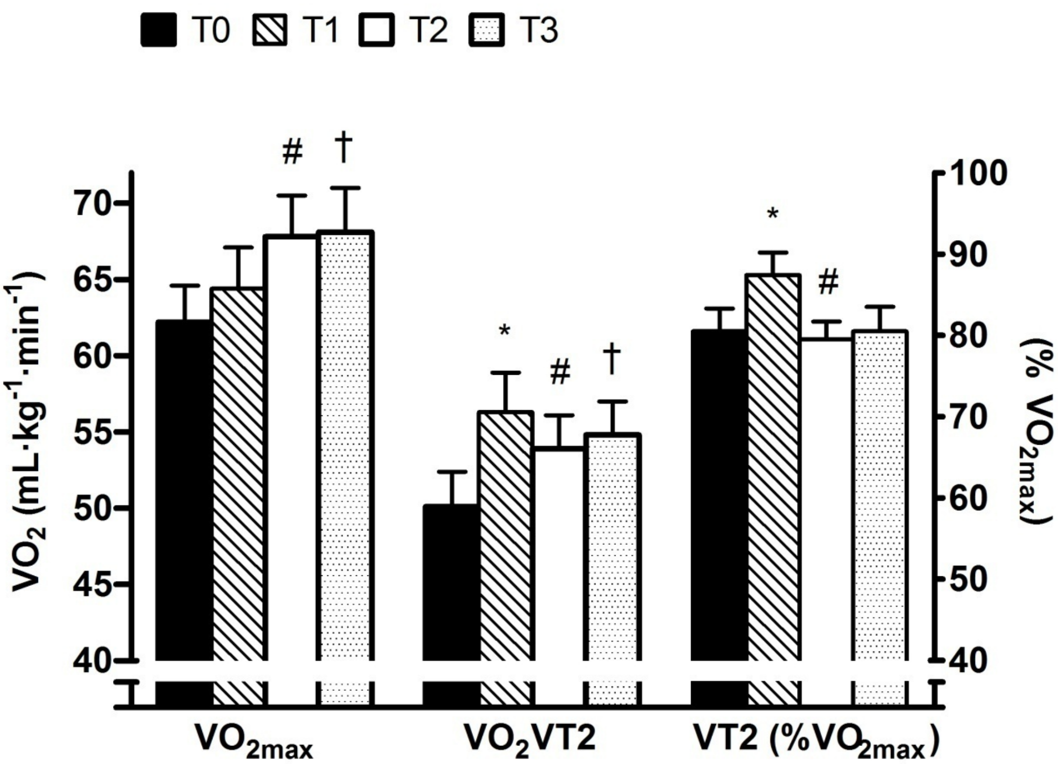

Fig. 3. Cambios en el VO_{2max}, VO_2VT2 y $VT2(\%VO_{2max})$ durante las 12 semanas del programa de entrenamiento. Los datos se presentan como media ± DE.
*Diferencias significativas entre T0 y T1
#Diferencias significativas entre T1 y T2
†Diferencias significativas entre T0 y T3

Cambios de fuerza y potencia

De T0 a T1, el 1RM mejoró significativamente (9.7 y 7.7 % para el PB y el DR respectivamente, $P < 0.01$), mientras que la $V_{45\%}$ se mantuvo estable en ambos ejercicios. Entre T1 y T2, no se detectaron cambios significativos en los valores de 1RM, mientras que la $V_{45\%}$ mejoró con tendencia a la significación (5.3%, $P = 0.077$ para el PB y 4.6%, $P = 0.082$ para el DR). Entre T2 y T3, los valores de 1RM descendieron significativamente un -4.6 y un -4.5% ($P < 0.05$) para el PB y el DR respectivamente. Simultáneamente, la $V_{45\%}$ mejoró significativamente ($P < 0.01$) un 11% en PB y un 7.1% en DR. Al comparar los resultados de T0 con T3 para estas variables, se detectaron mejoras significativas ($P < 0.05$) en el 1RM en PB (4.2%) y en DR (5.3%) También se detectaron aumentos significativos ($P < 0.001$) en la $V_{45\%}$ en PB (14.4%) y en DR (10%) (Fig. 4).

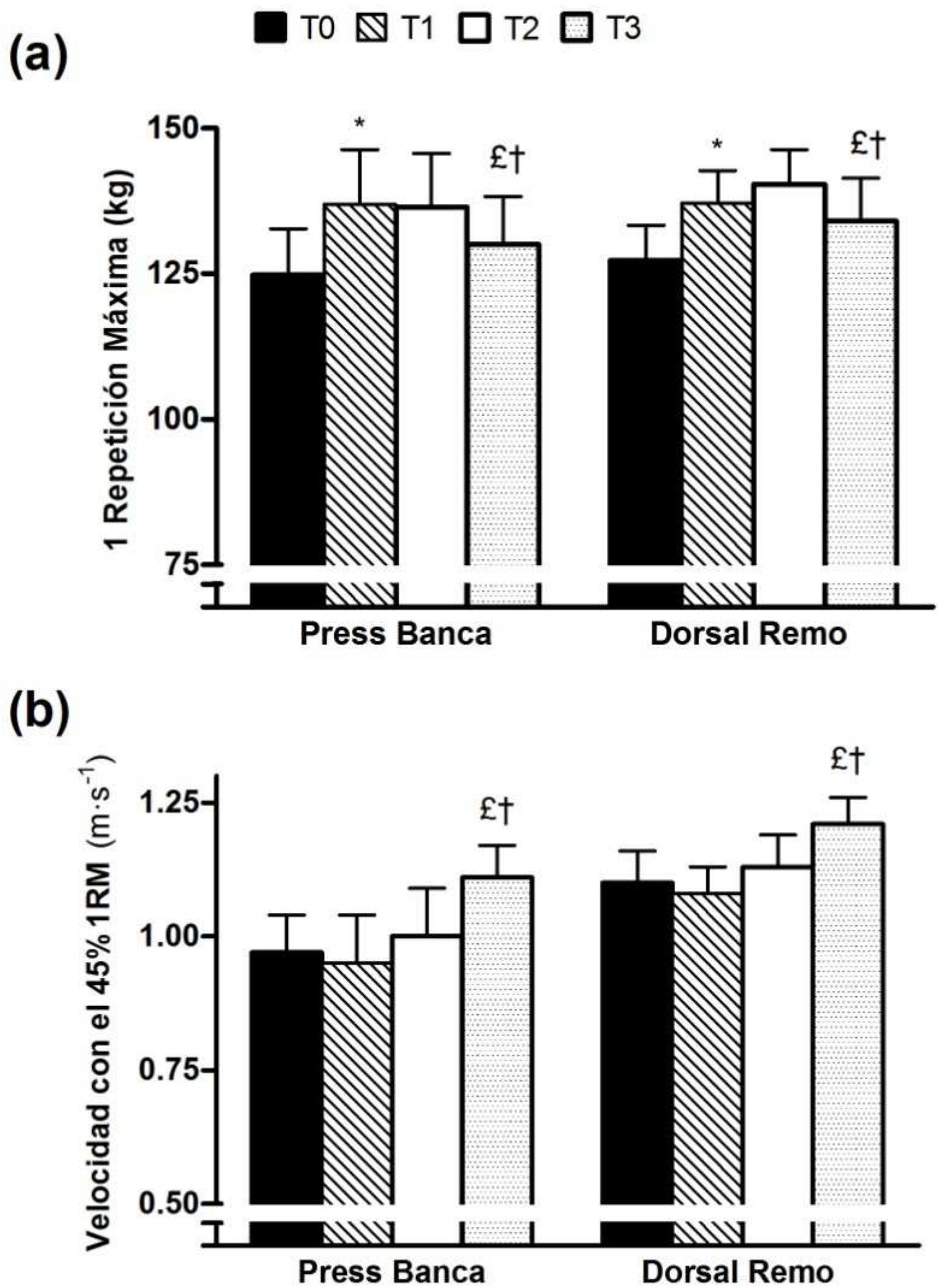

Fig. 4. Cambios en el 1RM (a) y en la $V_{45\%}$ (b) en los ejercicios de press banca y de doral remo durante las 12 semanas del programa de entrenamiento. Los datos se presentan como media ± DE.
*Diferencias significativas entre T0 y T1
£Diferencias significativas entre T2 y T3
†Diferencias significativas entre T0 y T3

Discusión

Este estudio detalla los cambios en las variables de resistencia, antropométricas y de fuerza relacionados con el rendimiento de kayakistas de élite durante 12 semanas de un ciclo de entrenamiento periodizado. Los resultados obtenidos por esta investigación son importantes y únicos debido al nivel internacional de los atletas, las elevadas demandas de fuerza y resistencia de su disciplina deportiva, así como por la escasez de este tipo de estudios en la literatura científica. El principal hallazgo de esta investigación fue que un ciclo de 12 semanas de entrenamiento periodizado fue efectivo para producir adaptaciones positivas tanto en las variables de fuerza como en las de resistencia, mostrando que es posible llevar a cabo un desarrollo simultáneo de estas capacidades en relativamente cortos periodos de tiempo y en sujetos de alto nivel de rendimiento.

Estudios previos han determinado que la aplicación de una estructura periodizada de entrenamiento puede ser el mejor opción para minimizar las interferencias en el desarrollo simultáneo de la fuerza y resistencia (Baker 2001; Docherty y Sporer 2000). Sin embargo, el conocimiento sobre cuál puede ser la estructura ideal de estas periodizaciones en deportes que requieren el desarrollo de ambos componentes del rendimiento físico (fuerza y resistencia) es escaso. De acuerdo con el modelo propuesto por Docherty y Sporer (2000), en el presente estudio se decidió priorizar el desarrollo los diferentes componentes del rendimiento físico de forma secuencial en cada una de las fases de entrenamiento, por lo que las posibles interferencias en el desarrollo simultáneo de fuerza y resistencia podrían ser minimizadas. En particular, el programa de entrenamiento periodizado empleado en esta investigación evitó deliberadamente combinar el entrenamiento de hipertrofia muscular (el objetivo de entrenamiento en la F1) y el de potencia aeróbica (el objetivo de resistencia en la F2), ya que se ha comprobado que ambos métodos de entrenamiento producen prioritariamente adaptaciones fisiológicas opuestas a nivel periférico, e impiden al organismo un desarrollo óptimo y simultáneo de ambos componentes del rendimiento (Leveritt y cols. 1999). Así, mientras que el entrenamiento de hipertrofia produce aumentos de la síntesis de proteínas contráctiles en el músculo, causando un considerable estrés metabólico y hormonal a nivel celular, el entrenamiento de potencia aeróbica produce aumentos de la capacidad oxidativa del músculo (Docherty y Sporer 2000; Sale y cols.1990a). Por otro lado, el entrenamiento aeróbico de baja intensidad (75-85% del VO_{2max}), empleado normalmente para la mejora del VT2, puede producir mayores adaptaciones centrales de las que se pueden esperar menores interferencias con los métodos de entrenamiento de fuerza vía hipertrofia muscular (F1). El citado modelo también predice menores interferencias entre el entrenamiento de fuerza máxima o máxima potencia mecánica y el entrenamiento de potencia aeróbica (F3), ya que el estímulo de entrenamiento para el aumento de la fuerza muscular puede ser dirigido principalmente al sistema nervioso (aumento de la frecuencia de estímulo, cambios en la sincronización, aumento de del umbral de reclutamiento de unidades motoras, etc.), y no requieren una elevada demanda metabólica en el músculo. Por lo tanto, parece que la manipulación de la intensidad de entrenamiento de cada fase de la preparación es de vital importancia para evitar las posibles interferencias en el desarrollo simultáneo de fuerza y resistencia (Docherty y Sporer 2000).

A pesar de que el volumen total de entrenamiento de resistencia fue similar en las dos primeras fases de 5 semanas (52.7 h en F1 y 49.5 h en F2), la intensidad de entrenamiento fue marcadamente diferente. Mientras en F1 la mayor parte del volumen de entrenamiento se llevó a cabo para mejorar el VT2 (57% del tiempo total de entrenamiento sobre Z2), en la F2 se priorizó el desarrollo de la potencia aeróbica (44% del tiempo total de entrenamiento sobre Z3). Esta especificidad del entrenamiento parece ser la responsable de los cambios producidos en las variables cardiorrespiratorias durante cada una de las fases de entrenamiento. El VO_2VT2 fue la variable que mayores incrementos del rendimiento alcanzó durante F1 (12.4%), mientras que el VO_{2max} se incrementó de forma especialmente importante durante la F2 (5.3%) (Fig. 3). Los valores medios de VO_{2max} de 68.1 $mL \cdot kg^{-1} \cdot min^{-1}$ alcanzados tras las 12 semanas de entrenamiento son significativamente mayores que las obtenidas en estudios previos (en un rango de 54–60 $mL \cdot kg^{-1} \cdot min^{-1}$) llevados a cabo por otros autores con kayakistas de alto nivel y empleando ergometría y protocolos de valoración similares a los descritos en esta investigación (Bishop y cols. 2002; Fry y Morton 1991; Tesch y cols. 1983; Van Someren y Oliver 2002). Aunque el entrenamiento de resistencia llevado a cabo en F1 no fue orientado específicamente al desarrollo de la potencia aeróbica (Fig. 1), los aumentos significativos en el VO_{2max} de un 3.5% tras esta fase de entrenamiento (Fig. 3) puede ser debida a que los palistas se encontraban en un nivel de rendimiento especialmente bajo consecuencia de la fase de transición previa de 5 semanas. Las mejoras obtenidas en el VO_{2max} de un 5.3% en F2, se alcanzaron tras los incrementos del tiempo dedicado al entrenamiento de la potencia aeróbica, pasando de 5.3 a 21.8 h sobre la Z3. Los cambios observados en el VO_{2max} en tan sólo 12 semanas de entrenamiento (9.5% de incremento al comparar T0 y T3; Fig 3) son de magnitud similar a los descritos en el único estudio longitudinal previo llevado a cabo con palistas de nivel internacional (Tesch y cols. 1976), aunque esas mejoras se obtuvieron tras un periodo significativamente más largo de entrenamiento (8 meses).

De forma similar, la especificidad del entrenamiento de resistencia completada sobre la zona de VT2 durante la F1 (57% del tiempo total de entrenamiento en Z2; Fig. 1) produjeron importantes mejoras en el VO_2VT2 (12,4%). Durante la F2, coincidiendo con una importante reducción del tiempo de entrenamiento sobre la Z2 (únicamente 32%), los valores de VO_2VT2 descendieron significativamente un -4.3%, mientras que no se detectaron cambios en esta variable durante la F3. Por otro lado, una vez concluidos las 12 semanas del ciclo de entrenamiento, los valores VT2(%VO_{2max}) fueron idénticos a los de partida (80.5%), a pesar de que el VO_2VT2 fue significativamente mayor (aumentó de 50.1 a 54.8 $mL \cdot kg^{-1} \cdot min^{-1}$ de T0 a T3) (Fig. 3).

Las variables estrechamente relacionadas con el rendimiento específico en el paleo como la V_{max} y la V_{VT2}, aumentaron de forma similar y progresiva a lo largo de todo el ciclo de entrenamiento, hasta alcanzar mejoras del 6.2 y 4.4% entre T0 y T3, respectivamente (Tabla 4). Es destacable que la V_{max} mejoró de 15.1 a 15.5 km h^{-1} en las últimas dos semanas (F3), durante la fase de puesta a punto. La concentración media de ácido láctico detectada al final del test incremental en kayak ergómetro (13.0 ± 2.8 mmol L^{-1}) es similar a los resultados encontrados en la literatura (Bishop y cols. 2002; Tesch y cols. 1976; 1983) con valores comprendidos entre 13–16 mmol L^{-1}, en estudios llevados a cabo igualmente con kayakistas de alto nivel.

Las mejoras en los valores de 1RM en el ejercicio de press banca (9.7%; Fig. 4), tras 5 semanas de entrenamiento de fuerza orientado a la hipertrofia muscular en la F1, son similares a los descritos para este ejercicio en sujetos con entrenamiento moderado tras similares rutinas de entrenamiento concurrente en jugadores de baloncesto de categoría junior y jugadores de fútbol (entre 5.2 y 9.6%) (Drinkwater y cols. 2005; 2007), o jugadores de balonmano (16%) tras 6 semanas de entrenamiento (Marques y González-Badillo 2006). Cabe destacar que los aumentos de la fuerza dinámica máxima se obtuvieron a pesar de que los aumentos de la hipertrofia muscular durante estas 5 semanas fueron moderados, ya que únicamente el perímetro torácico mostró cambios significativos durante esta fase (Tabla 3). Las grandes mejoras obtenidas en la $V_{45\%}$ durante todo el ciclo (11% en PB y 7% en DR) ocurrieron principalmente durante la F3, donde el 80% del volumen total de entrenamiento de fuerza se destinó al trabajo con cargas de máxima potencia (Fig. 4). Durante la realización de este tipo de entrenamiento, el número de repeticiones completadas en cada serie fueron cuidadosamente contraladas monitorizando la velocidad de ejecución en cada una de las repeticiones, y facilitando un feedback inmediato al deportista. Cada serie de entrenamiento de potencia se dio por concluida cuando la velocidad media de la repetición descendió un 10% de la velocidad registrada para la repetición más rápida en cada serie (Tabla 2). Esto hizo posible obtener altos valores de potencia en unas pocas repeticiones por serie, estrategia que ha sido sugerida por varios autores (Baker y Newton 2007; Izquierdo y cols. 2006b; Tidow 1995) para la mejora de la potencia máxima en atletas de élite altamente entrenados. Por el contrario, la fuerza dinámica máxima descendió considerablemente en F3 (-4.5% en ambos ejercicios; Fig. 4) a pesar de que el 20% del total del entrenamiento durante esta fase se destinó al método de fuerza máxima (Fig. 2). Este hecho puede estar relacionado con la reducción del volumen y la intensidad de entrenamiento durante esta fase final de puesta a punto, y quizás sugiera la necesidad de proponer estímulos de alta intensidad para mantener las mejoras obtenidas en fuerza dinámica máxima en atletas de alto nivel. Los resultados obtenidos en la fuerza dinámica máxima, unidos a los elevados valores de VO_{2max} y VO_2VT2 hallados en este estudio confirman los grandes requerimientos de potencia aeróbica y de fuerza en las pruebas de piragüismo incluidas en el programa olímpico.

A pesar de que el tiempo total dedicado al entrenamiento de resistencia fue tres veces superior que el destinado al entrenamiento de fuerza, los valores de fuerza y potencia mejoraron constantemente a lo largo del ciclo de entrenamiento. Unido a la mencionada estrategia de priorizar el desarrollo de dos objetivos de la condición física en cada fase de entrenamiento (un objetivo de fuerza y otro de resistencia), las mejoras simultáneas en las variables de fuerza y resistencia observadas en el presente estudio, pueden ser explicadas por otros factores que creemos han ayudado a reducir las interferencias en el entrenamiento concurrente de fuerza y resistencia. Entre ellos destaca el control del volumen de entrenamiento y, especialmente, la limitación a tres sesiones de entrenamiento de fuerza semanales. Tal y como ha sido descrito en la introducción, estudios previos que analizaron el entrenamiento concurrente han demostrado que una elevada frecuencia de entrenamiento de fuerza puede comprometer las ganancias a nivel neuromuscular. Los resultados de esta investigación también destacan la importancia del orden y la secuencia de las sesiones de entrenamiento aeróbico y de fuerza, con objeto de minimizar los posibles efectos de interferencia (Leveritt y cols. 1999; 2000; Sale y cols. 1990b; Sporer y Wenger 2003). Por ello, una recuperación insuficiente entre sesiones de entrenamiento pueden limitar las adaptaciones simultáneas de fuerza y resistencia. La fatiga residual de una sesión de resistencia aeróbica previa podría provocar una disminución de la calidad del entrenamiento en la sesión posterior de fuerza, comprometiendo la capacidad del sistema neuromuscular para producir fuerza (Leveritt y cols. 1999) y/o reducir el volumen absoluto de entrenamiento de fuerza que pueda ser realizado en tales condiciones (Sale y cols. 1990b). Por lo tanto, y siguiendo las indicaciones que esbozaron Sporer y Wenger (2003), en el presente estudio se decidió programar las sesiones de fuerza antes que las sesiones de resistencia o, cuando no fuese posible, separar ambas sesiones de entrenamiento al menos 6-8 horas para permitir una adecuada reposición del glucógeno muscular.

Otros dos aspectos determinantes que se introdujeron en el diseño del programa de entrenamiento de fuerza fueron: a) evitar alcanzar la repetición del fallo en cada serie de entrenamiento y b) focalizar la atención para realizar cada repetición a la máxima velocidad concéntrica posible. Estas iniciativas se basan en los hallazgos de investigaciones previas (Cronin y Sleivert 2005; Folland y cols. 2002; Izquierdo y cols. 2006a), y tienen como principal objetivo maximizar las adaptaciones en el componente neural de la fuerza, así como para evitar inducir excesiva fatiga o estrés metabólico y mecánico en el deportista, que pudiera tener una influencia negativa en la calidad de las sesiones posteriores de entrenamiento. En el estudio de Sale y cols. (1990b), aunque detectaron aumentos similares de hipertrofia muscular al realizar el entrenamiento concurrente de fuerza y resistencia en el mismo día o en día diferentes, las ganancias de fuerza fueron superiores al realizar en el entrenamiento en días diferentes. Por lo tanto, parece que las adaptaciones neurales se ven perjudicadas cuando se combina el entrenamiento de fuerza y resistencia dentro de una misma sesión, por lo que para optimizar el rendimiento neuromuscular es necesario realizar el entrenamiento en un estado de recuperación de fatiga adecuado. Al igual que el entrenamiento concurrente de fuerza y resistencia llevado a cabo en este estudio, el entrenamiento periodizado puede beneficiar a los especialistas del kayak, canoa y remo en competiciones de corta duración, en cuyas programaciones se focaliza sobre el desarrollo de la fuerza máxima y la máxima potencia muscular en fases concretas del ciclo de entrenamiento.

En resumen, un ciclo de entrenamiento periodizado de doce semanas de duración, con entrenamiento concurrente de fuerza y resistencia, y con especial atención en priorizar el desarrollo de unos componentes concretos del rendimiento físico (hipertrofia muscular y VT2 en la F1; fuerza máxima y potencia aeróbica en la F2) parece ser efectivo para la mejora de las variables cardiorrespiratorias y neuromusculares en atletas de elite mundial.

Agradecimientos

Queremos agradecer a los profesionales del Centro Andaluz de Medicina del Deporte en Sevilla por su excelente apoyo técnico con el instrumental de laboratorio y su asistencia médica a los atletas. También queremos agradecer la dedicación, el esfuerzo y la profesionalidad de los deportistas que tomaron parte en esta investigación.

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Artículo II

“Efectos del desentrenamiento sobre las variables fisiológicas y de rendimiento en kayakistas de élite mundial: comparación entre dos estrategias de recuperación”

Efectos del desentrenamiento sobre las variables fisiológicas y de rendimiento en kayakistas de élite mundial: comparación entre dos estrategias de recuperación

Journal of Sports Science and Medicine 2009

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Resumen

Este estudio analiza los cambios en las variables fisiológicas, hormonales y de rendmiento en piragüismo tras una fase de 5 semanas de reducción (RE) o de cesión completa de entrenamiento (CE). Catorce kayakistas de elite mundial fueron asignados aleatoriamente a los grupos de RE (n = 7) o CE (n = 7) al final de la temporada de competiciones (T1). Se llevaron a cabo valoraciones de muestras sanguíneas y un test incremental maximal en kayak ergómetro en T1 y tras 5 semanas de RE o CE (T2). El consumo máximo de oxígeno (VO_{2max}) y el consumo de oxígeno en el segundo umbral ventilatorio (VT2) descensideron significativamente en el grupo de CE (-10.1% y -8.8%, respectivamente). También se observaron descensos significativos pero de menor magnitud en el grupo de RE (-4.8% y -5.7% respectivamente). La frecuencia cardiaca en VT2 mostró aumentos significativos en el grupo de CE (3.5%). Sin embargo no se detectaron cambios en la frecuancia cardiaca en VO_{2max} en ningún grupo. La concetración pico de ácido láctico en sangre se mantuvo sin cambios en ambos grupos en T2. La velocidad de paleo en VO_{2max} descendió significativamente en T2 en el grupo de CE (-3.3%), mientrras que la velocidad de paleo en VT2 descendió significativamente en ambos grupos (-5% y -4.2% para CE y RE, respectivamente). La frecuancia de paleo en VO_{2max} y en VT2 aumentó significativamente el grupo de CE un 5.2% y un 4.9%, respectivamente. La potencia de paleo en VO_{2max} y en VT2 descendió significativamente en ambos grupos, aunque los valores detectados tras el periodo de RE fueron superiores a los obervados tras la CE. Se detectó un descenso significativo de los niveles de cortisol (-30%) en ambos grupos, mientras que el grupo de RE expirementó aumentos superiores en el ratio testosterona / cortisol. Estos resultados indican que la estrategia de RE puede ser más efectiva que la completa CE para evitar excesisvos descensos en la función cardiovascular y el rendmiento específico en palistas de elite mundial.

Palabras Clave: Desentrenamiento, potencia aeróbica, kayak, parámetros de paleo, perfil hormonal.

Introducción

La periodización del entrenamiento en el deporte de alto nivel hace hincapié en la necesidad de incorporar en el programa periodos de regeneración tras la conclusión de los eventos principales de la temporada. El objetivo de estas fases es permitir una completa recuperación física y mental del deportista antes de comenzar un nuevo ciclo de entrenamiento (Bompa 1999; Issurin 2008). Sin embargo, no están claras las consecuencias que estas fases de recuperación de 4-6 semanas pueden tener sobre las variables fisiológicas y los parámetros que condicionan el rendimiento específico en deportistas de élite. La magnitud de los descensos del rendimiento detectados tras los periodos de desentrenamiento parecen estar relacionados con la estrategia de recuperación escogida (reducción o cesión completa de entrenamiento), el nivel de rendimiento actual, y el tiempo total bajo la influencia de estos periodos de reducción o ausencia de estímulos de entrenamiento (Mujika y Padilla 2000a; 2000b).

Los periodos de recuperación del entrenamiento se caracterizan en primer lugar por una alteración y descenso del rendimiento del sistema cardiorrespiratorio y metabólico durante el esfuerzo (Mujika y Padilla 2001). De acuerdo a los datos descritos en la literatura, la CE produce una rápida reducción de la potencia aeróbica, detectándose descensos del VO_{2max} entre el 6 y el 14% tras 3-6 semanas de CE en sujetos con gran experiencia en el entrenamiento (Coyle y cols. 1984; Martin y cols. 1986; Petibois y Déléris 2003), mientras que periodos más cortos de CE han producido descensos menos acusados (Houmard y cols. 1992; Houston y cols. 1979). Por el contrario, en sujetos con poca experiencia en el entrenamiento, los efectos residuales del entrenamiento parecen ser retenidos con mayor facilidad. En esta misma línea, no se detectaron cambios significativos en el VO_{2max} tras 3 semanas de CE (Moore y cols. 1987) o leves descensos (~7%) tras 4-6 semanas de CE (Hansen y cols. 2004; Marles y cols. 2007) en sujetos poco entrenados. Los descensos observados en la potencia aeróbica tras periodos de cesión completa de entrenamiento parecen estar relacionados en los descensos de los parámetros cardiorrespiratorios básicos como la volemia, el gasto cardiaco, volumen de eyección y la ventilación voluntaria máxima (Cullinane y cols. 1986; Martin y cols. 1986).

El tejido musculo-esquelético no es una excepción es estos efectos del desentrenamiento. La reducción en la densidad capilar (Houston y cols. 1979), la capacidad oxidativa (Mujika y Padilla 2001), la sección trasversal media de la fibra (Bangsbo and Mizuno 1988), la actividad EMG (Häkkinen y cols. 1981), la diferencia arterio-venosa del VO_2 (Coyle y cols. 1984), asi como cambios en los tipos de fibras (Larsson y Ansved, 1985) se han descrito en deportistas tras periodos de CE.

Con ánimo de reducir los efectos negativos que la ausencia de estímulos de entrenamiento pueda tener sobre el rendmiento deportivo, se han propuesto estrategias de reducción de entrenamiento (periodos durante los cuales el volumen y/o la intensidad se reducen significativamente) como alternativa a la cesión completa del entrenamiento, especialmente en deportistas de alto nivel (Mujika y Padilla 2000a; 2000b; Neufer y cols. 1987). No obstante, existe escasez de información sobre los efectos que tiene la RE en los parámetros fisiológicos y el rendimiento deportivo. Un número limitado de investigaciones (Hickson y cols. 1982; Neufer y cols. 1987) han llevado a cabo estudios para determinar los efectos del desentrenamiento con estrategias de reducción de entrenamiento. Estos estudios muestran que es posible reducir drásticamente el volumen y/o la frecuencia de entrenamiento durante cuatro semanas y mantener los niveles de VO_{2max}. Sin embargo, aunque una única sesión semanal de alta intensidad de 35 minutos fue efectiva para mantener el VO_{2max} en un grupo de deportistas bien entrenados en resistencia, la capacidad aeróbica (definida como el tiempo máximo hasta el agotamiento al 75% del VO_{2max}) descendió un 20% tras 4 semanas de este tipo de entrenamiento (Madsen y cols. 1993).

Por otra parte, generalmente es aceptado que el entrenamiento y competición en el deporte de alto nivel induce un considerable estrés del sistema neuroendocrino. La interacción de los porocesos anabólicos y catabólicos que tienen lugar como consecuancia del esfuerzo físico y la recuperación, jugan un papel vital en las adaptaciones fisiológcas al entrenamiento (Kraemer y Ratamess 2005). Se ha observado como cortos periodos de CE o RE han incrementado las concentraciones de hormonas anabólicas (ej. testosterona, hormona del crecimiento) y descensos en las catabólicas (ej. cortisol), posiblemente relacionada con la habilidad del organismo para luchar contra los procesos catabólicos y mejorar la reconstrucción tisular (Hortobágyi y cols. 1993). No obstante, no está clara la respuesta del sistema hormonal en deportistas de alto nivel, y en especialidades con grandes requerimientos de fuerza y resistencia como el piragüismo olímpico, tras periodos de CE o RE.

Para nuestro conocimiento, no existen estudios que hayan comparado los efectos de las estrategias de CE y RE sobre las variables fisiológicas y de rendimiento en deportistas de élite durante los periodos de recuperación entre temporadas. Por lo tanto, el objetivo de este estudio fue examinar los cambios fisiológicos, hormonales y de rendimiento tras 5 semanas de reducción o de cesión completa de entrenamiento en un grupo de kayakistas de élite mundial.

Método

Catorce hombres palistas de elite mundial (todos ellos finalistas de Campeonatos del Mundo, incluidos dos campeones olímpicos) tomaron parte de forma voluntaria en este estudio. La media (DE) de las características de los participantes fue la siguiente: edad 25.2 (2.5) años; altura 1.81 (0.04) m; masa corporal 84.2 (5.5) kg; experiencia en el entrenamiento 11.1 (2.7) años; volumen de paleo anual 4415 (374) km. Todos los sujetos tenían al menos 2 años de familiarización con los procedimientos de valoración empleados en la investigación, y todos ellos pertenecían al mismo equipo (Equipo Nacional Español de Piragüismo). Este estudio, que cumplió con la Declaración de Helsinki, fue aprobado por el Comité de Bioética de la Universidad de Sevilla, y para el cual se obtuvo un consentimiento informado de los deportistas antes de comenzar la investigación.

Entrenamiento previo

Todos los palistas realizaron una temporada completa de entrenamiento (47 semanas) que culminó con el Campeonato del Mundo de Aguas Tranquilas. Durante este periodo, los palistas completaron un programa periodizado de entrenamiento combinado de fuerza y resistencia, bajo la supervisión de entrenadores de piragüismos experimentados. El volumen de entrenamiento de fuerza durante estas 47 semanas ascendió a: 37.8 ± 2.6 h, 42 ± 3 sesiones, 840 ± 60 series y 7,560 ± 540 repeticiones de hipertrofia; 44.4 ± 3.2 h, 42 ± 3 sesiones, 642 ± 46 series y 2,600 ± 199 repeticiones de fuerza máxima; y 32.4 ± 1.1 h, 34 ± 2 sesiones, 488 ± 29 series y 2,673 ± 158 repeticiones de potencia máxima. El entrenamiento de resistencia se estructuró en 3 ciclos de 11-22 semanas de duración. El volumen total de entrenamiento fue de 264.1 ± 12.7 h a la velocidad de paleo correspondiente al 75-90% VO_{2max}, 39.9 ± 2.0 h entre 90-105% VO_{2max}, y 8.6 ± 0.6 h por encima del 105% VO_{2max}. Los atletas completaron entre 60-130 km (10-15 sesiones de paleo) a la semana.

Diseño Experimental

Todos los sujetos realizaron un test incremental maximal y hasta el agotamiento 25 días antes de comenzar el Campeonato del Mundo (T1), con objeto de evitar cualquier tipo de interferencia en la preparación de los palistas para esta competición, la más importante de la temporada. Igualmente, se tomaron muestras de sangre 5 días antes del comienzo del campeonato. Se repitieron las mismas valoraciones 5 semanas después de la conclusión del Campeonato del Mundo (T2). Una vez concluida la competición, cada participante se asigno aleatoriamente a los grupos de reducción de entrenamiento (RT; n = 7) y de cesión de entrenamiento (CE; n = 7). El grupo de CE no realizó ningún tipo de entrenamiento físico durante las siguientes 5 semanas, mientras el grupo de RE realizó únicamente una sesión de entrenamiento de fuerza y dos de resistencia semanales. La sesión de entrenamiento de fuerza (miércoles) estaba compuesta por 3 series de 10 repeticiones con el 12RM individual en los ejercicios de press banca, dorsal remo y sentadilla, respetando tres minutos de recuperación entre series. El entrenamiento de resistencia consintió en dos sesiones de 40 minutos a intensidad moderada (~80% VO_{2max}), una de carrera (lunes) y otra de paleo (viernes). En los cuatro días restantes no se realizó ningún tipo de entrenamiento físico. El volumen de entrenamiento semanal que realizó el grupo de RE supuso aproximadamente el 20% del volumen medio de entrenamiento semanal completado durante las 47 semanas precedentes.

Test incrmental maximal en kayak ergómetro

Tras 5 minutos de calentamiento a una velocidad de 9 $km \cdot h^{-1}$, los sujetos completaron un test incremental de paleo hasta el agotamiento en un kayak-ergómetro (Dansprint ApS, Denmark; drag resistance coefficent = 35). El primer escalón del test se completó a 11.5 $km \cdot h^{-1}$, y la velocidad se incrementó 0.5 $km \cdot h^{-1}$ cada minuto. Cada sujeto adaptó libremente la frecuencia de paleo (FP) a sus necesidades, y se registró continuamente su evolución durante el test con un frecuenciómetro (Interval 2000, Nielsen-Kellerman, USA). La frecuencia cardiaca (FC) se monitorizó empleando un pulsómetro telemétrico estándar (S610i; Polar Electro Oy, Finland) y se tomaron registros cada 5 segundos. Se alentó a los palistas a realizar el máximo esfuerzo voluntario y completar el mayor número posible de escalones del test. La prueba se dio por concluida cuando el sujeto detuvo el paleo voluntariamente por extenuación, o por la incapacidad de mantener la velocidad requerida. Se realizó un análisis de gases respiración a respiración empleando para ello un analizador de gases Jaeger Oxycon Pro system (Erich Jaeger, Germany). Se calibró el analizador de gases usando una mezcla de gases 4.95% CO_2-95.05% N_2 (BOC Gases, Surrey, UK), y el sensor de volumen usando una jeringa de calibración 3-L.

Variables fisiológicas

El VO_{2max} se definió como la media de los dos valores consecutivos más elevados de VO_2 registrados durante los últimos 90 segundos de esfuerzo. Todos los sujetos cumplieron los siguientes criterios para establecer el VO_{2max}: a) relación de intercambio respiratorio (RER) mayor de 1.1, y b) FC pico mayor o igual al 90% de FC máxima en base a la predicción por edad. Se determinó el segundo umbral ventilatorio (VT2) empleando el criterio de un incremento en ambos equivalentes ventilatorios ($V_E \cdot VO_2^{-1}$ y $V_E \cdot VCO_2^{-1}$) y el descenso de la presión del CO_2 al final de la fase espiratoria ($PETCO_2$). Dos observadores independientes realizaron las determinaciones del VT2. En caso de discrepancia, un tercer observador realizó la determinación. La FC en VO_{2max} (FC_{max}) y la FC en VT2 (FC_{VT2}) también se obtuvieron para cada palista. Se tomaron muestras de sangre capilar en el lóbulo de la oreja durante la recuperación del test (minutos 1, 3, 5, 7, 10 y 12) para determinar la concentración pico de ácido láctico ($[La^-]_{pico}$), empleando para ello un analizador de lactato (LF20; Dr. Lange, France).

Variables relacionadas con el rendimiento en piragüismo

Se establecieron las variables relacionadas con el rendimiento en piragüismo durante el test incremental maximal: velocidad de paleo en VO_{2max} (V_{max}), velocidad de paleo en VT2 (V_{VT2}), frecuencia de paleo en VO_{2max} (FP_{max}), frecuencia de paleo en VT2 (FP_{VT2}), potencia de paleo en VO_{2max} (Pw_{max}), y potencia de paleo en VT2 (Pw_{VT2}).

Análisis de sangre

En T1 y T2 se tomaron muestras de sangre venosa (10 mL) de la vena antecubital empleando para ello vacutainers y agujas estériles. Todas las muestras fueron obtenidas a la misma hora del día en todos los sujetos (8-9 h) tras 12 horas de ayuno nocturno y un día de recuperación previo. La muestras de sangre se recogieron en tubos con EDTA, centrifugadas a 800 g durante 10 min a 4ºC, y el plasma se almacenó a -80ºC hasta que se analizaron por duplicado la testosterona total (T) y el cortisol (C) por radioinmunoanálisis (125I RIA kits, DiaSorin, MN, USA). Las varianzas inter e intra ensayo de la testosterona fueron menores de 3.5% y 7.0% respectivamente; mientras que las varianzas inter e intra ensayo del cortisol fueron menores de 4.6% y 5.8% respectivamente.

Análisis estadístico

Se emplearon métodos estadísticos estándar para el cálculo de los valores medios y de las desviaciones estándar (DE). Se realizó Un ANOVA de dos factores para establecer los cambios absolutos en las variables estudiadas entre ambos test (T1 y T2) y entre grupos (CE y RE). En todo caso, se consideró un nivel de confianza de $P \leq 0.05$.

Resultados

Variables fisiológicas

No se detectaron diferencias significativas entre grupos en T1 en ninguna variable fisiológica estudiada. Tras 5 semanas de desentrenamiento, el VO_{2max} descendió un -11.3% (desde 69.1 ± 3.9 a 61.3 ± 2.7 $mL \cdot kg^{-1} \cdot min^{-1}$; $P < 0.01$) y -5.6% (desde 68.5 ± 3.0 a 64.6 ± 3.1 $mL \cdot kg^{-1} \cdot min^{-1}$; $P < 0.05$) en los grupos de CE y RE respectivamente. Los valores de VO_{2max} en T2 fueron significativamente mayores ($P < 0.05$) en el grupo de RE comparado con el grupo de CE. El VO_2 en VT2 descendió en el grupo de CE (-8,8%, $P < 0.01$) y en el de RE (-5.7%, $P < 0.05$) (Fig. 1). La FC_{VT2} aumentó en el grupo de CE entre T1 y T2 (3.5%, $P < 0.05$). y detetctaron valores significativamente mayores ($P < 0.05$) de esta variable en el grupo de CE comparado con el grupo RE en T2. No se obervaron diferencias significativas en el VT2(%VO_{2max}), FC_{max}, y $[La^-]_{pico}$ entre T1 y T2 en ningún grupo (Tabla 1 y Fig. 1).

Variables relacionadas con el rendimiento en piragüismo

Entre T1 y T2, la V_{VT2} descenció tanto en el grupo de CE (-5.0%) como en el de RE (-4.2%) ($P < 0.05$), mientras que la V_{max} descendió de forma significativa únicamente en el grupo de CE (-3.3%, $P < 0.05$). La FP_{max} y FP_{VT2} mostraron incrementos significativos en el grupo de CE (5.2% y 4.9%, $P < 0.05$, respectivamente). No se registraron diferencias significativas en T1 entre grupos en la variable de Pw_{max}, aunque tras las 5 semanas de desentreamiento, la Pw_{max} descendió significativamente en ambos grupos (-7.9% y -3.9%, $P < 0.05$, en CE y RE respectivamente). Además, los valores alcanzados en T2 fueron significativamente mayores ($P < 0.05$) en el grupo de RE que en el de CE. Entre T1 y T2, las magnitud de los descensos en la Pw_{VT2} (-11%, $P < 0.05$) fue idéntica en ambos grupos. Los valores de Pw_{VT2} fueron significativamente mayores ($P < 0.05$) en el grupo de RE comparado con el CE tanto en T1 como en T2 (Tabla 1).

Tabla 1. Cambios en los parámetros cardiorrespiratorios y de rendimiento en kayak.

	CE		RE	
	T1	T2	T1	T2
FC_{max} (pulsaciones·min^{-1})	193 ± 6	195 ± 6	189 ± 7	192 ± 5
FC_{VT2} (pulsaciones·min^{-1})	173 ± 5	179 ± 4*	171 ± 4	174 ± 4 †
$[La^-]_{pico}$ (mmol·L^{-1})	14.0 ± 3.3	15.6 ± 4.6	13.1 ± 3.1	14.0 ± 3.4
V_{max} (km·h^{-1})	15.1 ± 0.5	14.6 ± 0.2*	15.2 ± 0.3	14.9 ± 0.3
V_{VT2} (km·h^{-1})	14.1 ± 0.3	13.4 ± 0.3*	14.2 ± 0.3	13.6 ± 0.2*
FP_{max} (paladas·min^{-1})	96 ± 3	101 ± 3*	98 ± 5	101 ± 3
FP_{VT2} (paladas·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** †

Los datos se presentan como media ± DE. CE: Cesión de Entrenamiento (n = 7); RE: Reducción de Entrenamiento (n = 7). Diferencias significativas: * P < 0.05 comparado con T1; ** P < 0.01 comparado con T1; † P < 0.05 comparado con TC.

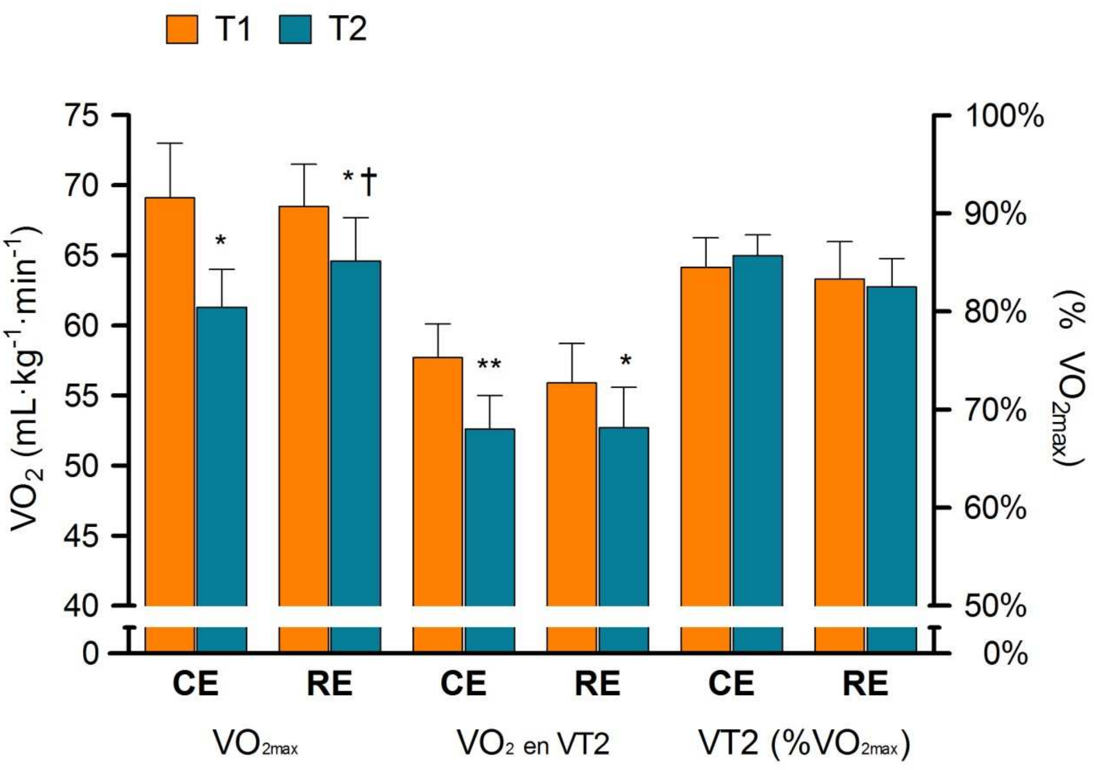

Fig. 1. Cambios en el VO_{2max}, VO_2 en VT2 y VT2 (%VO_{2max}) tras un periodo de 5 semanas de cesión (CE) o reducción de entrenamiento (RE). Diferencias significativas: * $P < 0.05$ comparado con T1; ** $P < 0.01$ comparado con T1; † $P < 0.05$ comparado con CE.

Concentración hormonal basal

Entre T1 y T2 se detectaron descensos similares (-30%, $P < 0.01$) en los niveles de cortisol en ambos grupos (CE y RE). Los niveles de testosterona incremenaron de forma similar en los dos grupos entre T1 y T2, aunque no fueron cambios significativos. El ratio T:C aumentó ($P < 0.01$) en el grupo de CE (62.5%) y en el de RE (67.6%), hallándose valores significativamente mayores en el grupo de RE que el grupo de CE en T2 ($P < 0.05$).

Tabla 2. Cambios en la concentración hormonal basal.

	CE		RE	
	T1	T2	T1	T2
Cortisol (nmol · L^{-1})	486.9 ± 70.6	339.0 ± 53.3**	460.0 ± 77.3	320.8 ± 58.4**
Testosterona (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**†

Los datos se presentan como media ± DE. CE: Cesión de Entrenamiento (n = 7); RE: Reducción de Entrenamiento (n = 7). Diferencias significativas: * P < 0.05 comparado con T1; ** P < 0.01 comparado con T1; † P < 0.05 comparado con TC.

Discusión

Esta investigación muestra que un periodo de 5 semanas de reducción de entrenamiento en un grupo de kayakistas de élite es una estrategia eficaz para minimizar los graves descensos en los parámetros cardiorrespiratorios y de rendimiento específico del paleo que tienen lugar si se detiene completemente el entrenamiento durante este mismo periodo de tiempo. Además, un corto periodo de desentrenamiento, como el descrito en esta investigación, parece elevar el estado anabólico del organismo mediante una disminución de los niveles de cortisol y un moderado incremento de los niveles de testosterona en ambos grupos (CE y RE). Aunque la estrategia de RE empleada en esta investigación parece ser más efectiva que la completa CE para limitar la magnitud de las pérdidas en la potencia y capacidad aeróbica, nuestros resultados muestran que realizando únicamente dos cortas sesiones semanales de resistencia a intensidad moderada durante 5 semanas, no es un estímulo suficiente para prevenir descensos significativos en el rendmiento aeróbico en deportistas de élite mundial. En línea con los resultados de nuestro estudio, investigaciones previas mostraron que el mantenimiento de un mínimo de estímulos de entrenamiento de alta intensidad durante los periodos de RE y puesta a punto, es de vital importancia para retener las adaptaciones al entrenamiento (Neufer 1989).

Los descensos en la potencia aeróbica detectados en el grupo de CE (-11%) fueron similares a los encontrados en estudios previos que examinaron los efectos de cortos periodos de CE en deportistas con altamente entrenados (Coyle y cols. 1984; Godfrey y cols. 2005; Martin y cols. 1986; Petibois y Déléris 2003). Por contra, llevar a cabo dos sesiones de entrenamiento de resistencia semanales a una intensidad moderada (~80% VO_{2max}) permitió a los los deportistas del grupo de RE reducir significativamente los descensos del VO_{2max} que ocurrieron en el grupo de CE. Estos hallazgos están en la línea de los encontrados por otros autores quienes estudiaron los cambios en los parámetros fisiológicos de deportistas bien entrenados tras periodos de una marcada reducción de entrenamiento. Así mismo, tras una temporada completa de entrenamiento, Neufer y cols. (1987) encontraron que 4 semanas de RE (realizando una tercera parte del volumen habitual de entrenamiento, con tres sesiones semanales) permitió a nadadores de alto nivel preservar parte de los efectos residuales de entrenamiento sobre la potencia aeróbica, un mantenimiento que no ocurrió realizando únicamente una sesión semanal. Igualmente, Hickson y cols. (1982) mostraron que era posible mantener los niveles de VO_{2max} con una reducción máxima de dos terceras partes del volumen de entrenamiento.

Nuestra estrategia de RE no permitió prevenir descensos en el VO_2 en VT2 (-5.7%),aunque estos descensos fueron menores de los sufridos por el grupo de CE (-8.8%). Estos hallazgos son similares a los encontrados por Godfrey y cols. (2005) quienes detectaron descensos de un ~5% en el VO_2 a nivel del umbral láctico tras 8 semanas de CE en un remero camepeón olímpico. Igualmente, Galy y cols. (2003) mostraron que un periodo de 6 semanas de RE con bajo volumen e intensidad de entrenamiento fueron suficientes para mantener los niveles de VO_{2max}, pero no para evitar descensos significativos en el VO_2 en VT2 en un grupo de deportistas bien entrenados.

El uso fraccional de la potencia aeróbica, un criterio válido para evaluar la capacidad aeróbica, permaneció sin cambios en ambos grupos (CE y RE), debido a las descensos proporcionales que acontecieron en el VO_{2max} y el VO_2 en VT2 durante las 5 semanas de desentrenamiento, unos hallazgos que están en la línea de los obervados por Godfrey y cols. (2005).

Los incrementos del un ~3% encontrados en la FC_{VT2} en el grupo de CE son similares a los obervados en estudios previos tras periodos de CE en deportistas bien entrenados (Coyle y cols. 1986; Houmard y cols. 1992; Madsen y cols. 1993).

Por el contrario, la FC_{max} y la FC_{VT2} no experimentaron cambios en el grupo de RE de nuestro estudio. Los incrmentos de la FC submáxima durante los periodos de CE parecen estar relacionados con el intento del organismo de mantener el gasto cardiaco durante el esfuerzo, y contrarrestar las reducciones del volumen de eyección (Coyle y cols. 1984; Mujika y Padilla 2000a; 2000b; Mujika y Padilla 2001).

La ausencia de cambios significativos en la $[La^-]_{pico}$ en ambos grupos (CE y RE) tras las 5 semanas de desentrenamiento son resultados similares a los descritos por Marles y cols. (2007), quienes no encontraron cambios en la $[La^-]_{pico}$ tras 6 semanas de RE en deportistas con poca experiencia en el entrenamiento. No obstante, otras resultados publicados mostraron incrementos de la actividad de la LDH tras periodos de CE (Claude y Sharp 1991; Costill y cols. 1985; Neufer y cols. 1987).

Existe muy poca información en la literatura sobre los efectos de las estrategias de CE y RE en el rendmiento específico del paleo durante los periodos de recuperación entre temporadas. Aunque nuestra estrategia de RE permitió a los palistas evitar pérdidas significativas de la V_{max}, esta no fue suficiente para prevenir las pérdidas de la V_{VT2} próximas al 4.5%. Madsen y cols. (1993) encontraron que el tiempo límite al 75% del VO_{2max} desendió un 21% tras 4 semanas de RE en sujetos bien entrenados. Igualmente, tras 2 semanas de CE, Houston y cols. (1979) detectaron que el tiempo de esfuerzo a una intensidad submáxima descendió un 25%; mientras que Petibois y Déléris (2003) detectaron descensos de la velocidad aeróbica máxima (~20%) tras 5 semanas de CE en remeros de alto nivel.

En el presente estudio, la FP_{max} y la FP_{VT2} aumentaron únicamente de forma significativa en el grupo de CE, hallazgos similares a los encontrados por Issurin y cols. (1986), quienes detectaron aumentos de la frecuencia de paleo durante una fase de puesta a punto en piragüistas de alto nivel. Así mismo, Neufer y cols. (1987) detectaron incrementos de la FP a intensidades máximas y submáximas tras periodos de RE en nadadores de alto nivel. Los aumentos de la frecuencia de ciclo detectados en el presente estudio pueden ser debidos a los descensos del rendmiento neuromuscular como consecuancia de las 5 semanas de desentrenamiento. En este sentido, es posible que la capacidad del palista de generar fuerza en cada palada se viera afectada, y tuviese como resultado la necesidad de incrementar la FP a fin de mantener la potencia y/o la velocidad requerida. Sin embargo, estos aumentos significativos en la FP_{max} y la FP_{VT2} detectados en el grupo de CE no fueron suficientes para compensar las supuestas pérdidas de rendmiento neuromuscular y los valores de V_{max}, V_{VT2} y Pw_{max}, que descendieron en mayor medida en el grupo de CE que el grupo de RE.

A pesar de que en el presente estudio la estrategia de RE permitió a los palistas mantener parte de los efectos residuales de entrenamiento, la Pw_{max} y Pw_{VT2} sufrieron descensos significativos en ambos grupos (CE y RE). Estos descensos en la potencia de paleo indican que una sesión de entrenamiento de fuerza y dos de resistencia semanales fueron claramente insuficientes para mantener el rendmiento específico en kayakistas de élite.

Tras el periodo de desentrenamiento, la concentración de testosterona basal mostró aumentos no significativos en el grupo de CE (13%) y de RE (16%). Por otro lado, los niveles de cortisol descendieron significativamente en ambos grupos (30%). Como resultado, el ratio T:C aumentó drásticamente (Tabla 2). Todos estos cambios en el balance hormonal basal tras este corto periodo de desentrenamiento son un claro indicativo de un aumento de la actividad androgénica-anabólica (Kraemer y Ratamess 2005), y parece estar relacionada con la reacción del organismo para combatir los procesos catabólicos inducidos por los altos niveles de estrés físico y mental acumulados durante la temporada precedente. El ratio T:C en T2 fue significativamente mayor en el grupo de RE comparado con el grupo de CE, datos que de nuevo sugieren la conveniencia de incorporar algunos estímulos de entrenamiento en los periodos de recuperación entre temporadas para evitar el avance de las procesos catabólicos (ej. atrofia muscular) o para mejorar aún más los procesos anabólicos. Los aumentos detectados en el ratio T:C y la reducción de los niveles de cortisol están en la línea de los resultados encontrados por Hortobágyi y cols. (1993) tras 14 días de inactividad. Por contra, otras investigaciones no detectaron cambios en la concentraciones basales de testosterona, cortisol o ratio T:C tras 4-12 semanas de CE (Häkkinen y cols. 1985; Izquierdo y cols. 2007; Kraemer y cols. 2002). Todo ello sugiere que la respuesta hormonal tras los periodos de desentrenamiento parecen estar relacionados con el nivel inicial de los deportistas y el tiempo total bajo restricción o cesión de estímulos de entrenamiento. Aunque llevar a cabo la valoración de las concentraciones hormonales basales de forma aislada tiene sus limitaciones, estas se han empleado en numerosas estudios de entrenamiento de fuerza (Kraemer y Ratamess 2005), especialmente en aquellos estudios que monitorizaron el entrenamiento de deportistas durante la temporada de competición y la fase de transición. Además, somos conscientes de que aunque el ratio T:C ha sido comúnmente empleado para indicar el posible estado anabólico o catabólico en relación al rendimiento, esto parece ser una simplificación excesiva (Izquierdo y cols. 2006).

Conclusión

En conclusión, una estrategia de RE compuesta por una sesión de fuerza y dos de resistencia semanales a intensidad moderada fue efectiva para atenuar los adversos efectos del desentrenamiento obervados tras la cesión completa de entrenamiento en las variables fisiológicas y especificas de rendmiento en piragüismo como el VO_{2max}, FC_{VT2}, ratio T:C, FP_{max}, FP_{VT2}, V_{max}, Pw_{max}, y la Pw_{VT2} en palistas de élite mundial. Con el aumento cada vez mayor del número de competiciones y las elevadas exigencias del deporte moderno en alto nivel, llevar a cabo un programa de mantenimiento en el periodo de recuperación entre temporadas parece ser una medida apropiada para prevenir excesivas pérdidas en el rendimiento aeróbico, así como para facilitar la recuperación del estado de forma en ciclos de entrenamiento posteriores.

Puntos clave

- Cortos periodos (5 semanas) de cesión de entrenamiento en deportistas de alto nivel producen mayores descensos del rendmiento en las variables fisiológicas y en los parámaetros de rendmiento que una estrategia de reducción de entrenamiento.
- Tras una temporada completa de entrenamiento y competición, las estrategias de CE y RE facilitan un aumento de la actividad adrogénica-anabólica del organismo.
- Estos resultados sugieren la conveniencia de realizar un programa de mantenimiento durante los periodos de transición entre temporadas, con ánimo de de minimizar los descensos de rendimiento en la resistencia.

Agradecimientos

Queremos agradecer a los profesionales del Centro Andaluz de Medicina del Deporte en Sevilla por su excelente apoyo técnico con el instrumental de laboratorio y su asistencia médica a los atletas. También queremos agradecer la dedicación, el esfuerzo y la profesionalidad de los deportistas que tomaron parte en esta investigación.

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Artículo III

“Efectos fisiológicos de la puesta a punto y el desentrenamiento en kayakistas de elite mundial”

Efectos fisiológicos de la puesta a punto y el desentrenamiento en kayakistas de elite mundial

Medicine and Science in Sports and Exercise 2009

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Resumen

Propuesta: Este estudio analiza los cambios en las variables neuromusculares, de resistencia y de composición corporal durante 4 semanas de puesta a punto y las subsiguientes 5 semanas de reducción (RE) o cesión total de entrenamiento (CE). **Métodos**: Catorce kayakistas de elite mundial fueron asignados aleatoriamente a los grupos de RE (n = 7) o CE (n = 7). Se realizaron valoraciones de una repetición máxima (1RM), velocidad media de la fase concéntrica con el 45% del 1RM ($V_{45\%}$) en los ejercicios de press banca (PB) y dorsal remo (DR), así como mediciones de la composición corporal al comienzo (T0) y al final (T1) de un programa de entrenamiento de 43 semanas de duración, tras la fase de puesta a punto del Campeonato del Mundo (T2) y finalmente al concluir las fases de RE o CE (T3). Se realizó un test incremental maximal en kayak ergómetro para la determinación del consumo máximo de oxígeno en T0, T1 y T3. **Resultados**: Tras la fase de puesta a punto, no se observaron cambios significativos en el 1RM o en la $V_{45\%}$. El grupo de CE mostró mayores descensos en la 1RM (-8.9% y -7.8%, $P < 0.05$, para el PB y el DR respectivamente) que los observados para el grupo de RT (-3.9% y -3.4%). Los descensos en la $V_{45\%}$ en el PB y el DR fueron mayores para el grupo de CE (-12.6% y -10.0%) que para el grupo RT (-9.0% y -6.7%). Se observaron incrementos en el sumatorio de ocho pliegues cutáneos tras la RE y CE, mientras que los descensos en la potencia aeróbica fueron menores tras la RE (-5.6%) que tras la CE (-11.3%). **Conclusión**: Cortos periodos de cesión de entrenamiento producen mayores descensos en la fuerza máxima y especialmente en la $V_{45\%}$ que la RE en atletas de alta cualificación. Estos resultados sugieren la necesidad de realizar un programa de mantenimiento para evitar descensos a nivel neuromuscular en aquellos casos en los que sea necesaria una fase de recuperación del entrenamiento.

Palabras clave: Cesión de entrenamiento; reducción de entrenamiento; fuerza máxima; potencia muscular; piragüismo.

Introducción

Llevar a cabo una fase de puesta a punto antes de los objetivos prioritarios de competición es una estrategia generalmente aceptada por entrenadores e investigadores. Esta fase se caracteriza por una marcada reducción del volumen de entrenamiento mientras que la intensidad se mantiene elevada (Gibala y cols. 1994; Izquierdo y cols. 2007; Mujika y Padilla 2000a; Mujika y Padilla 2003; Mujika y cols. 2004). Estos aumentos del rendimiento durante las fases de puesta a punto se han asociado a una mejora de los procesos de recuperación (Gibala y cols. 1994; Mujika y Padilla 2003; Mujika y col. 2004). Estudios previos han descrito mejoras de la fuerza isocinética a baja velocidad de los flexores del codo tras 8 días de puesta a punto en sujetos con una moderada experiencia en el entrenamiento de fuerza (Gibala y cols. 1994). Izquierdo y cols. (2007) encontraron que la fase de puesta a punto permitió aumentos de la fuerza máxima y potencia muscular en el tren inferior y superior tras un entrenamiento periodizado en deportistas con experiencia en el entrenamiento de fuerza. Igualmente, varios estudios que examinaron los efectos de las fases de puesta a punto en deportistas de resistencia atribuyeron las mejoras en el rendimiento a los incrementos de los niveles de fuerza y potencia muscular (Hooper y cols. 1998; Neary y cols. 2003; Shepley y cols. 1992; Trappe y cols. 2000).

La incorporación de periodos de cesión de entrenamiento tras la conclusión del evento principal de la temporada es una práctica común en muchas especialidades deportivas. Estos periodos de transición tienen como principal objetivo permitir una adecuada recuperación a nivel físico y psíquico del deportista antes de comenzar una nueva temporada de entrenamiento y competición. En esta situación, la reducción de entrenamiento normalmente es la opción preferida ya que parece ser una estrategia más efectiva para evitar, al menos parcialmente, el impacto negativo que supone la insuficiencia de estímulos de entrenamiento sobre el rendimiento físico del deportista (Mujika y Padilla 2000b). La magnitud de los descensos del rendimiento detectados tras los periodos de desentrenamiento parecen estar relacionados con la estrategia de recuperación escogida (reducción o cesión completa de entrenamiento), el nivel de rendimiento actual, y el tiempo total bajo la influencia de estos periodos de reducción o ausencia de estímulos de entrenamiento (Mujika y Padilla 2000a; 2000b; Mujika y Padilla 2001).

Novedosas investigaciones en este campo parecen indicar que el rendimiento neuromuscular es más susceptible a los descensos en deportistas de alto nivel en comparación con deportistas con una experiencia en el entrenamiento baja o moderada (Izquierdo y cols. 2007; Mujika y Padilla 2001). En sujetos con experiencia en el entrenamiento de fuerza se han detectado descensos en la fuerza dinámica máxima en ejercicios típicos del entrenamiento de fuerza como son el press banca (9%), sentadilla (10-12%) y la extensión de rodilla (12%) tras 4-8 semanas de CE (Häkkinen y cols. 1981; Häkkinen y cols. 1985; Izquierdo y cols. 2007) mientras que en periodos más cortos de CE (2 semanas) los descensos de fuerza muscular parecen ser menores (Hortobágyi y cols. 1993) o inexistentes (Houmard y cols. 1993). Por el contrario, en atletas con poca experiencia, las mejoras de fuerza obtenidas con el entrenamiento parecen retenerse con mayor facilidad tras cortos periodos de CE (4-6 semanas) (Houston y cols. 1983; Kraemer y cols. 2002; Terzis y cols. 2008). Además, los periodos de desentrenamiento parecen afectar en mayor medida a los valores de potencia muscular en comparación con la fuerza muscular (Izquierdo y cols. 2007; Kraemer y cols. 2002; Neufer y cols. 2007), especialmente en atletas altamente entrenados, aunque también se han documentado incrementos en el índice de manifestación de fuerza (IMF) (Ishida y cols. 1990) y cambios en la composición muscular hacia tipos de fibra más rápidas (Andersen y cols. 2005; Trappe y cols. 2000) como consecuencia del desentrenamiento.

Hasta la fecha, la mayoría de las investigaciones que han estudiado los cambios neuromusculares producidos por las fases de puesta a punto y desentrenamiento han empleado sujetos sedentarios o con poca experiencia en el entrenamiento. Por ello, existe una escasez de conocimiento a cerca de las consecuencias que estas puestas a punto y cortos periodos de desentrenamiento tienen sobre el rendimiento neuromuscular en deportistas altamente entrenados, con elevadas exigencias de fuerza y resistencia como son los kayakistas de especialidades olímpicas.

Por lo tanto, el objetivo de este estudio fue examinar los cambios en los parámetros de fuerza muscular, velocidad de desplazamiento ante cargas de máxima potencia, composición corporal y sobre la potencia aeróbica producidos por un periodo de 5 semanas de CE o RE tras un programa de entrenamiento periodizado de 43 semanas y 4 semanas de puesta a punto en un grupo de kayakistas de élite mundial.

Método

Muestra

Catorce hombres palistas de elite mundial (todos ellos finalistas de Campeonatos del Mundo, incluidos dos campeones olímpicos) tomaron parte de forma voluntaria en este estudio. La media (DE) de las características de los participantes fue la siguiente: edad 25.2 (2.5) años; altura 1.81 (0.04) m; masa corporal 84.2 (5.5) kg; experiencia en el entrenamiento11.1 (2.7) años; volumen de paleo anual 4415 (374) km. Todos los sujetos tenían al menos 2 años de familiarización con los procedimientos de valoración empleados en la investigación, y todos ellos pertenecían al mismo equipo (Equipo Nacional Español de Piragüismo). Este estudio fue aprobado por el Comité de Bioética de la Universidad de Sevilla, y se obtuvo un consentimiento informado de todos los deportistas antes de comenzar la investigación.

Diseño del estudio

Tras una temporada completa (43 semanas) de entrenamiento concurrente de fuerza y resistencia, los palistas completaron 4 semanas de puesta a punto (TAP) con objeto de maximizar su rendimiento en el Campeonato del Mundo de Aguas Tranquilas, competición que se había establecido como el principal objetivo de la temporada. Tras concluir este evento, comenzó inmediatamente una fase de desentrenamiento (DTR) de 5 semanas. Durante esta fase de DTR la mitad de los palistas cesaron totalmente los estímulos de entrenamiento (CE) y la otra mitad realizaron únicamente una sesión de entrenamiento de fuerza y dos de resistencia semanales (RE). Los deportistas fueron agrupados en función de la masa corporal, experiencia en el entrenamiento y la carga de una repetición máxima (1RM) en los ejercicios de press banca (PB) y dorsal remo (DR) y se asignaron aleatoriamente a los grupos de RE (N = 7) o CE (N = 7). Los participantes fueron convocados en el laboratorio en cuatro ocasiones diferentes a lo largo del estudio con objeto de evaluar las variables fisiológicas y de rendimiento seleccionadas (Fig. 1). Se llevaron a cabo valoraciones del 1RM, velocidad media de desplazamiento ante el 45% del 1RM y de composición corporal antes de comenzar la temporada (semana 0; T0), al comienzo de la fase de TAP (semana 44; T2), la semana correspondiente al Campeonato del Mundo (semana 47; T2), y finalmente tras la fase de DTR (semana 53, T3). Igualmente se llevó a cabo un test incremental maximal en kayak ergómetro en T0, T1 y T3.

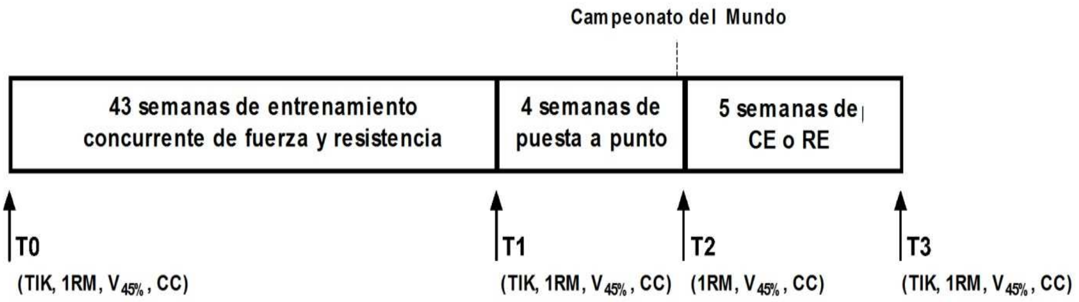

Fig. 1. Diseño del estudio y calendario de valoraciones. CE: Cesión de Entrenamiento; RE: Reducción de Entrenamiento; TIK: Test Incremental en kayak ergómetro; 1RM: test de fuerza una repetición máxima; $V_{45\%}$: velocidad con el 45% del 1RM; CC: valoración de la composición corporal.

Programa de entrenamiento

Desde la semana 1 hasta la semana 43 los palistas tomaron parte en un programa de entrenamiento concurrente de fuerza y resistencia, bajo la supervisión de entrenadores profesionales con varios años de experiencia en el entrenamiento de piragüistas. El entrenamiento de fuerza se estructuró en cuatro ciclos periodizados de 10-12 semanas, durante los cuales se completaron secuencialmente tres fases diferentes de entrenamiento de fuerza: hipertrofia (8-10 repeticiones, 4-5 series, 70-75% del 1RM, 2 minutos de recuperación entre series); fuerza máxima (3-4 repeticiones, 3-4 series, 85-90% del 1RM, 4 minutos de recuperación entre series); y potencia máxima (5-8 repeticiones, 4-5 series, 45-60% del 1RM, 4 minutos de recuperación entre series). Se emplearon 5 ejercicios principales: PB, DR, press de hombros, dominadas y sentadilla. Se evitó alcanzar la repetición del fallo en todas las series de entrenamiento de hipertrofia y fuerza máxima, y se motivó constantemente a los palistas para que realizasen la fase concéntrica de cada repetición a la máxima velocidad voluntaria. En las sesiones de entrenamiento de potencia máxima, cada serie se dio por concluida cuando la velocidad media descendía por debajo del 10% de la mejor repetición (la repetición con la fase concéntrica más rápida). El volumen total de entrenamiento durante las primeras 43 semanas ascendió a: 37.8 ± 2.6 h, 42 ± 3 sesiones, 840 ± 60 series y 7,560 ± 540 repeticiones de entrenamiento de hipertrofia; 41.8 ± 3.3 h, 38 ± 3 sesiones, 608 ± 48 series y 2,492 ± 197 repeticiones de entrenamiento de fuerza máxima; y 30.0 ± 1.1 h, 30 ± 2 sesiones, 450 ± 30 series y 2,475 ± 165 repeticiones de entrenamiento de máxima potencia. El entrenamiento de resistencia se estructuró en 3 ciclos de 11-22 semanas de duración. El volumen total de entrenamiento de resistencia que realizaron los palistas ascendió a 249.2± 13.2 h de paleo a la velocidad correspondiente al 75-90% del VO_{2max}, 35.7 ± 2.2 h entre el 90-105% del VO_{2max}, y 7.1 ± 0.6 h por encima del 105% VO_{2max}. Los palistas completaron entre 60-130 km (10-15 sesiones) a la semana.

La fase de TAP consistió en 4 semanas de descenso progresivo del volumen y un incremento de la intensidad de entrenamiento. Durante esta fase los palistas completaron dos sesiones de entrenamiento de fuerza semanales: a) una sesión de fuerza máxima 90-95% 1RM (3-4RM), 2-4 repeticiones por serie, y 2-3 series por ejercicio; b) una sesión de potencia máxima con el 45% del 1RM (PB, DR) o el 60% 1RM (sentadilla), 5-8 repeticiones y 3-4 series. Durante esta fase de TAP, los palistas realizaron únicamente los ejercicios de PB, DR y sentadilla. El tiempo total de entrenamiento de fuerza fue 2.6 ± 0.3 h, 34 ± 2 series y 108 ± 4 repeticiones de fuerza máxima; y 2.4 ± 0.2 h, 38 ± 5 series y 198 ± 34 repeticiones de potencia máxima. Además, los palistas completaron 5-10 sesiones de paleo semanales, durante las cuales se priorizó el entrenamiento de alta intensidad, mientras el volumen de entrenamiento se reducía progresivamente hasta un 50% del volumen habitual de entrenamiento. El volumen total de entrenamiento durante la fase de TAP ascendió a 14.3 ± 0.6 h de paleo a la velocidad correspondiente al 75-90% VO_{2max}, 4.2 ± 0.1 h entre el 90-105% VO_{2max} y 1.5 ± 0.3 horas por encima 105% VO_{2max}. Además los palistas realizaron tres días de competición al final de esta fase.

Finalmente, durante la fase de DTR, el grupo de CE detuvo completamente cualquier tipo de entrenamiento físico durante las siguientes 5 semanas, mientras que el grupo de RE realizó únicamente una sesión de entrenamiento de fuerza y dos sesiones de entrenamiento de resistencia a la semana. Durante este periodo no hubo control sobre la dieta de los deportistas. Las sesiones de entrenamiento de fuerza llevadas a cabo por el grupo de RE estaban compuestas por 3 series de 10 repeticiones con el 70-75% del 1RM de cada palista (10-12RM) en los ejercicios de PB, DR y sentadilla, respetando 3-min de recuperación entre series. El volumen de entrenamiento de resistencia consistió en una sesión de paleo y otra de carrera de 40 minutos a intensidad moderada (~80% VO_{2max}). En los cuatro días restantes no se realizó entrenamiento físico alguno.

Valoraciones

Las valoraciones se llevaron a cabo a lo largo de tres días consecutivos: composición corporal y test incremental maximal en kayak ergómetro (día 1), 1RM (día 2) y velocidad media de desplazamiento ante el 45% del 1RM (día 3). Para cada tipo de test se llevaron a cabo los mismos procedimientos y protocolos de calentamiento en cada ocasión. Las valoraciones se realizaron a la misma hora del día (10-12 h) y bajo similares condiciones ambientales (20-22ºC y 55-65% de humedad). La correlación test-retest interclase para todas las medidas practicadas en este estudio fueron mayores de 0.93, con coeficientes de variación en un rango de 0.9% a 3.3%.

Composición corporal

Las medidas antropométricas practicadas fueron: talla, masa corporal, pliegues cutáneos (tríceps, subescapular, suprailiaco, abdominal, muslo anterior, pierna medial, supraespinal y bíceps braquial). Todas ellas fueron tomadas por el mismo investigador experimentado, de acuerdo con las directrices de la International Society for the Advancement of Kineanthropometry (ISAK) (2006). El porcentaje graso y la masa libre de grasa se estimaron empleando la fórmula de Carter y Yuhasz (1984).

Test incremental maximal

Tras 5 minutos de calentamiento a una velocidad de 9 $km \cdot h^{-1}$, los sujetos completaron un test incremental de paleo hasta el agotamiento en un kayak-ergómetro (Dansprint ApS, Denmark). El primer escalón del test se completó a 11.5

$km \cdot h^{-1}$, y la velocidad se incrementó 0.5 $km \cdot h^{-1}$ cada minuto**.** Cada sujeto adaptó libremente la frecuencia de paleo (FP) a sus necesidades. Se alentó a los palistas a realizar el máximo esfuerzo voluntario y completar el mayor número posible de escalones del test. Se realizó un análisis de gases respiración a respiración empleando para ello un analizador de gases Jaeger Oxycon Pro system (Erich Jaeger, Germany). El VO_{2max} se definió como la media de los cuatro valores consecutivos más elevados de VO_2 hacia el final de la prueba.

Valoración de la fuerza dinámica máxima y la velocidad ante cargas de máxima potencia

Los procedimientos de valoración empleados en el presente estudio pueden encontrarse en investigaciones previas (García-Pallarés y cols. 2009). En resumen, el 1RM se determinó en los ejercicios de PB y DR en peso libre. Estos ejercicios fueron elegidos ya que son los más empleados en los entrenamientos de fuerza de piragüistas, a la vez que son útiles para valorar la fuerza y potencia de acciones musculares opuestas del tren superior (empuje y tracción). La carga más pesada que cada sujeto pudo levantar, sin ningún tipo de ayuda externa, fue considerada su 1RM. El día siguiente se evaluó en ambos ejercicios la velocidad media de la fase concéntrica con el 45% del 1RM establecido previamente. Esta carga coincide con la resistencia que maximiza la potencia mecánica media para ejercicios del tren superior (Baker y cols. 2001; Cronin y Sleivert 2005). Lo palistas realizaron 2 series de 3 repeticiones con el 45% del 1RM, respetando 5 minutos de pausa entre series. La velocidad media de la fase concéntrica fue medida por un trasductor lineal de posición (MuscleLab, Ergotest Technology, Oslo, Norway). La $V_{45\%}$ se definió como la velocidad media de las tres mejores repeticiones de cada sujeto.

Análisis Estadístico

Se emplearon métodos estadísticos estándar para el cálculo de los valores medios y de las desviaciones estándar (DE). Se realizó un análisis de la varianza factorial 2 x 4 con objeto de evaluar los cambios absolutos en las variables estudiadas entre los diferentes test (T0, T1, T2 y T3) y entre grupos (CE y RE). Se calculó el Tamaño del Efecto (TE) para los cambios en los grupos TC y RT entre T3 y T2 como la diferencia entre las medias divididas por la desviación estándar media para los dos grupos. En todo caso, se consideró un nivel de confianza de $P \leq 0.05$.

Resultados

No se observaron diferencias significativas en T0 entre los grupos CE y RE en ninguna de las siguientes variables: masa corporal, masa libre de grasa, experiencia en el entrenamiento, VO_{2max}, 1RM en PB y DR, o la V45% en los ejercicios PB y DR.

Composición corporal

Los cambios en la composición corporal se muestran en la Tabla 1. Se observaron descensos significativos ($P < 0.05$) en T1 en el sum de 8 pliegues para ambos grupos (CE y RE). Tras la fase de TAP se detectaron descensos no significativos en el sum de 8 pliegues en el grupo de CE (-4.9%) y de RE (-5.3%) al comparar T2 y T1. En T3, no se observaron cambios significativos en la masa corporal en ningún grupo al comparar con T2; no obstante se detectaron incrementos significativos ($P < 0.05$) en el sum de 8 pliegues para el grupo de CE (22.8%, TE = 3.12) y de RE (23.2, TE = 2.75). Tras la fase de DTR, no se observaron diferencias entre grupos en la magnitud de los cambios en el sum de 8 pliegues; mientras que se observó una interacción (grupo x tiempo) para la masa libre de grasa con descensos significativamente mayores para el grupo de CE (-3%, $P < 0.05$) comparado con el de RT (-0.1%, n.s).

Tabla 1. Evolución de los cambios en la composición corporal.

		T0	T1	Cambio T0-T1 (%)	T2	Cambio T1-T2 (%)	T3	Cambio T2-T3 (%)
CE	Masa corporal (kg)	85.6 ± 5.8	85.0 ± 5.4	-0.7	85.2 ± 5.8	0.2	85.0 ± 4.5	-0.2
	Masa libre de grasa (kg)	74.4 ± 2.7	75.9 ± 2.9	2.0	76.5 ± 2.9	0.8	74.2 ± 2.8#	-3.0
	Sum de 8 pliegues (mm)	72.3 ± 5.1	59.0 ± 4.4*	-18.4	56.1 ± 4.0	-4.9	68.9 ± 4.2#	22.8
RE	Masa corporal (kg)	86.7 ± 4.9	84.7 ± 5.5	-2.3	84.3 ± 4.8	-0.5	86.7 ± 4.6	2.8
	Masa libre de grasa (kg)	75.8 ± 2.9	76.0 ± 2.9	0.3	76.1 ± 2.7	0.2	76.2 ± 2.7†	0.1
	Sum de 8 pliegues (mm)	70.1 ± 4.5	56.8 ± 4.3*	-19.0	53.8 ± 4.5	-5.3	66.3 ± 4.6#	23.2

Los valores se muestran como media ± DE. Pliegues: tríceps, subscapular, suprailiaco, abdominal, muslo anterior, pierna medial, supraespinal y bíceps braquial.
CE: grupo de Cesión de Entrenamiento (N = 7); RE: grupo de Reducción de Entrenamiento (N = 7); T0 = semana 0, comienzo de la temporada; T1 = semana 44, comienzo de la fase de puesta a punto; T2 = semana 47, Campeonato del Mundo; T3 = semana 53, justo después de la fase de desentrenamiento.
Diferencias significativas: *al comparar T1 con T0; # T3 con T2; † mayor que el grupo de CE en el mismo test (P < 0.05).

Fuerza Muscular

Se detectaron aumentos significativos (P < 0.05) en el 1RM y en la $V_{45\%}$ en los ejercicios de PB y DR para ambos grupos al comparar T1 con T0 (Fig. 2A). En T2, tras concluir la fase de TAP, no se observaron cambios significativos en el 1RM o en la $V_{45\%}$ en ningún grupo. Tras la fase de DTR, se observó una interacción (grupo x tiempo) en el 1RM, con descensos significativamente mayores para el grupo de CE (-8.9% y -7.8%, P < 0.05, TE = -1.81 y -1.98, para los ejercicios de PB y DR, respectivamente) que el grupo de RE (-3.9% y -3.4%, n.s., TE = -0.67 y -0.87). Los descensos en el $V_{45\%}$ en los ejercicios de PB y DR fueron mayores en el grupo de CE (-12.6% y -10.0%, TE = -2.15 y -1.67 respectivamente) que los observados par el grupo de RE (-9.0% y -6.7%, TE = -1.67 y -0.67). No se detectaron diferencias significativas entre grupos en la magnitud de los cambios en la $V_{45\%}$ (Fig. 2B).

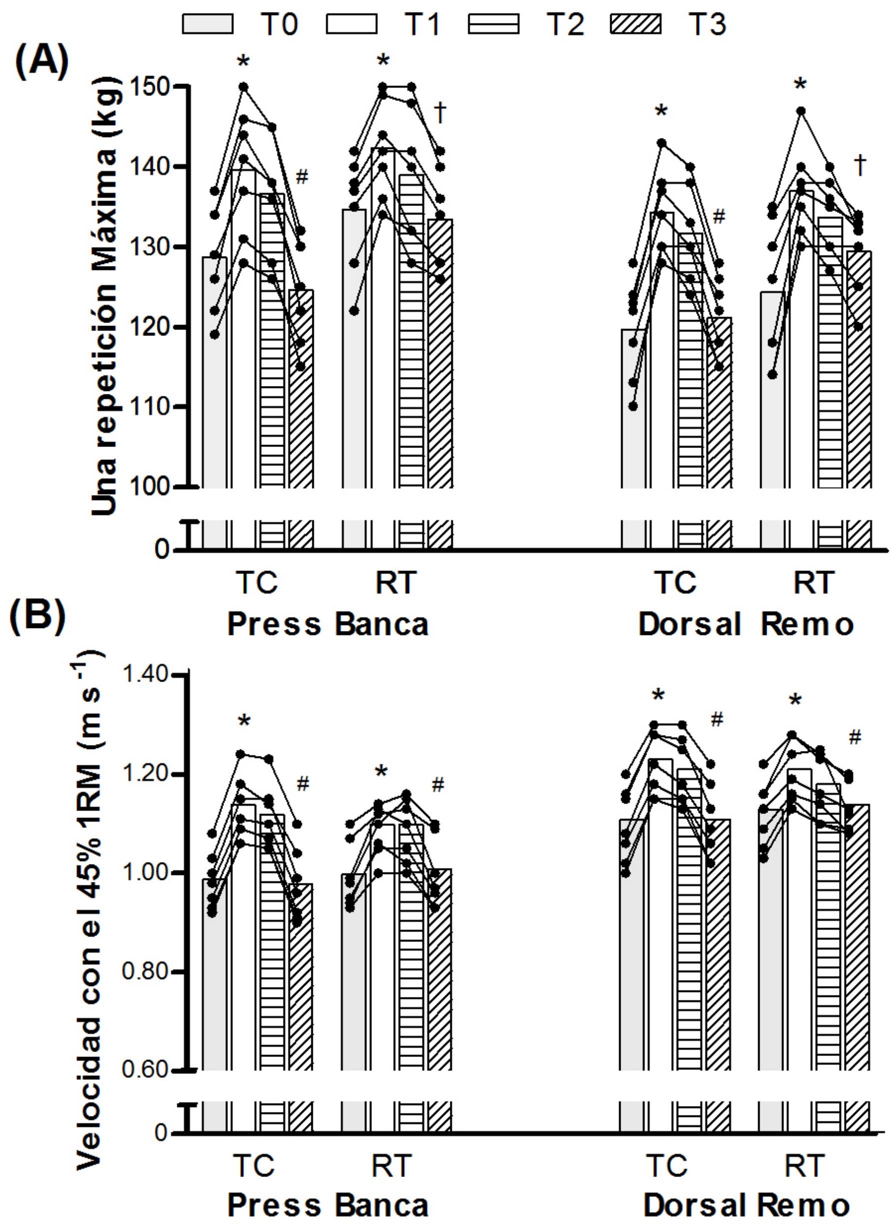

Fig. 2. Evolución de los cambios en el test de una repetición máxima (1RM) (**A**), y velocidad alcanzada con el 45% del 1RM (**B**) en los ejercicios de press banca y dorsal remo. CE: grupo de Cesión de Entrenamiento (N = 7); RE: grupo de Reducción de Entrenamiento (N = 7). Los valores se muestran como media ± DE. Diferencias significativas: * al comparar T1 con T0; # T3 con T2; † mayor que el grupo de CE en el mismo test ($P < 0.05$).

Potencia aeróbica máxima

Al comparar T1 con T0 se observaron incrementos significativos ($P < 0.05$) en el VO_{2max} tanto en CE (8.8%, de 63.5 a 69.1 mL·kg^{-1}·min^{-1}) como en RT (8.3%, de 63.2 a 68.5 mL·kg^{-1}·min^{-1}). Tras la fase DTR, se observó una interacción (grupo x tiempo) en el VO_{2max} con descensos significativamente mayores para el grupo de CE (-11.3%, de 69.1 a 61.3 $mL \cdot kg^{-1} \cdot min^{-1}$, $P < 0.05$, TE = -2.36) comparado con el grupo de RE (-5.6%, de 68.5 a 64.6 $mL \cdot kg^{-1} \cdot min^{-1}$, n.s., TE = -1.28). La evolución de los cambios en el VO_{2max}, en relación a la masa libre de grasa se muestra en la Fig. 3.

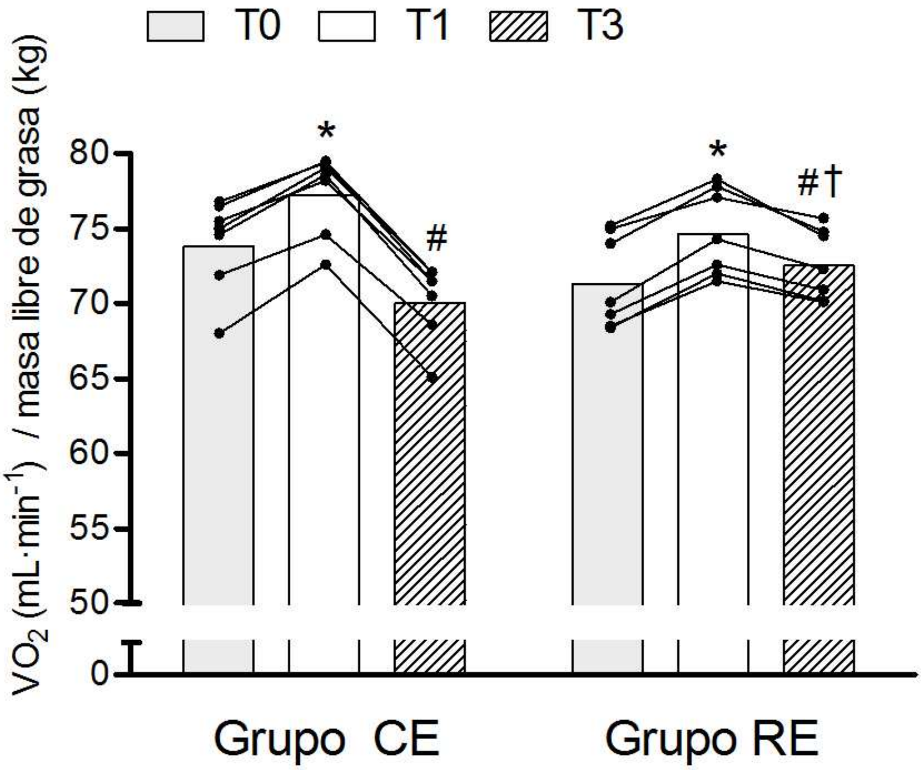

Fig. 3. Evolución de los cambios en el VO_{2max} en relación a la masa libre de grasa. CE: grupo de Cesión de Entrenamiento (N = 7); RE: grupo de Reducción de Entrenamiento (N = 7). Los valores se muestran como media ± DE. Diferencias significativas: * al comparar T1 con T0; # T3 con T2; † mayor que el grupo de CE en el mismo test ($P < 0.05$).

Discusión

Este estudio examina los efectos de una fase de puesta a punto (4 semanas) y la posterior fase de desentrenamiento (5 semanas) sobre el rendimiento de las variables neuromusculares, de composición corporal y de resistencia en un grupo de kakakistas de elite mundial cuya especialidad (piragüismo) requiere niveles muy elevados de fuerza muscular y potencia aeróbica. En un estudio previo nuestro grupo mostró (García-Pallarés y cols. 2009) que un programa de entrenamiento periodizado puede ser efectivo para el desarrollo simultáneo de la fuerza y resistencia aeróbica en kayakistas de élite, no obstante no existe suficientes investigaciones que analicen los efectos que estas fases de puesta a punto y los cortos periodos de desentrenamiento pueden tener sobre las variables neuromusculares y de rendimiento que condicionan el éxito en deportistas de elite. Los principales hallazgos del presente estudio fueron que un periodo de 5 semanas de una marcada reducción de entrenamiento en un grupo de piragüistas de élite, parecen ser efectivos para minimizar los drásticos descensos de los niveles de fuerza que tienen lugar tras una fase de cesión completa de entrenamiento de la misma duración, así como para permitir mantener los valores de masa libre de grasa en niveles próximos a los habituales. No obstante, los niveles de velocidad con el 45% del 1RM fueron más difíciles de mantener en ambos grupos, aunque el grupo de RE puedo prevenir parte de los grandes descensos que ocurrieron el grupo de CE. Las 4 semanas de puesta a punto fueron efectivas para mantener la fuerza dinámica máxima y la $V_{45\%}$ en los palistas, pero no para producir cambios positivos. Estos datos indican que a pesar de que se detectaron descensos del rendimiento en ambos grupos (CE y RE) entre T2 y T3, la cesión total de entrenamiento produjo mayores pérdidas de rendimiento neuromuscular que los que se detectaron tras la estrategia de reducción de entrenamiento.

Debido al aumento del número de competiciones y las elevadas exigencias del deporte moderno en alto nivel, una excesiva pérdida de rendimiento neuromuscular durante los periodos de transición entre temporadas puede provocar descensos importantes en el rendimiento de los atletas para los siguientes ciclos de entrenamiento. Además, la reducción del volumen de entrenamiento que generalmente se realiza durante las fases de puesta a punto pueden aumentar las citadas pérdidas de la condición física. Para deportistas de élite, en el presente estudio se han detectado pérdidas significativas de fuerza (descensos del -8.9% y -7.8% del 1RM en PB y DR, respectivamente) tras 5 semanas de cesión total de entrenamiento. Por el contrario, la práctica de una sesión semanal de entrenamiento de fuerza permitió al grupo de RE reducir en más de la mitad la magnitud de las caídas de fuerza máxima (3.9% en PB y 3.4% en DR) (Fig. 2A). Las pérdidas no significativas de fuerza máxima durante la fase de puesta a punto (~2% en ambos grupos y ejercicios) pueden ser explicadas por la gran reducción del volumen de entrenamiento de fuerza que se llevó a cabo durante estas 4 semanas en deportistas del más alto nivel. Los descensos observados en los valores de fuerza dinámica máxima para el grupo de CE tras la fase de DTR, fueron similares a los encontrados por otros autores en deportistas experimentados en el entrenamiento de fuerza tras 4 semanas de desentrenamiento: 10% en sentadilla completa (Häkkinen y Komi 1993), 9% en PB y 6% en media sentadilla (Izquierdo y cols. 2007). Periodos más largos de CE (8 semanas) parecen resultar en descensos más pronunciados en la fuerza, tal y como observaron Häkkinen y cols. (1981), quienes detectaron descensos de la fuerza de un 11.6 y 12.0% en sentadilla y extensión de rodilla respectivamente. Sin embargo, tras periodos más cortos de desentrenamiento las pérdidas de fuerza muscular han demostrado ser mínimas (Hortobágyi y cols. 1993; Houmard y cols. 1993).

La $V_{45\%}$ experimentó descensos significativos tras las 5 semanas de la fase de DTR, pero se mantuvo inalterable durante la fase de puesta a punto (TAP). Este hecho parece mostrar que el periodo de TAP empleado en el presente estudio fue efectivo para mantener la velocidad ante cargas de máxima potencia pero no permitió aumentos del rendimiento en esta variable, hallazgos similares a los descritos por Izquierdo y cols. (2007) tras una fase similar de TAP de 4 semanas de duración. En el grupo de CE, la $V_{45\%}$ descendió un -12.6% y un -8.3% en los ejercicios de PB y DR respectivamente (Fig. 2B). La estrategia de RE únicamente permitió amortiguar las caídas abruptas de la $V_{45\%}$ detectadas en el grupo de CE, registrándose para el grupo de RE unas caídas del -9.2% para PB y -6% para DR. Estos hallazgos muestran que los periodos de desentrenamiento producen mayores caídas en la potencia muscular que las descritas para la fuerza máxima (Izquierdo y cols. 2007; Kraemer y cols. 2002; Neufer y cols. 1987), y sugiere la necesidad de incluir en los programas de RE estímulos específicos de entrenamiento para mantener los niveles de potencia máxima en estos deportistas de alto nivel. Estos resultados parecen sugerir que los niveles de potencia muscular sufren descensos más acusados de su rendimiento que los valores de fuerza máxima en deportistas de élite durante un mismo periodo de tiempo. Estos resultados son similares a los descritos por Fry y cols. (2006), quienes también encontraron descensos significativos a nivel neuromuscular tras provocar el sobreentrenamiento en atletas con gran experiencia en el entrenamiento de fuerza. Estos datos enfatizan la necesidad de establecer la carga óptima de entrenamiento en cada fase de la periodización en deportistas de alto nivel.

Los incrementos detectados en el sum de 8 pliegues (~23%) tras la fase de DTR en ambos grupos fueron mayores que los descritos en la literatura para deportistas experimentados tras 2-6 semanas de CE (Tabla 1) (Hortobágyi y cols. 1993; Izquierdo y cols. 2007; Terzis y cols. 2008). Estas diferencias pueden atribuirse a diferentes factores: la ausencia (CE) o la insuficiencia de entrenamiento (RE) aeróbico durante la fase de desentrenamiento; los valores especialmente bajos de masa grasa detectados en los kayakistas durante la semana de la competición principal de la temporada (T2); y la ausencia del control sobre la dieta de los deportistas durante la fase de desentrenamiento. Las caídas de la masa libre de grasa de un 3% tras la CE son resultados similares a los descritos previamente (Allen 1989; Häkkinen y cols. 1981), que detectaron descensos de la masa muscular tras 6-8 semanas de cesión total de entrenamiento. A diferencia del grupo de CE, la masa libre de grasa permaneció estable en el grupo de RE (Tabla 1), resultados que apoyan la conveniencia de realizar un programa de mantenimiento durante la fase de desentrenamiento.

Resulta destacable el hecho de que los descensos del VO_{2max} tras las fase de DTR fueron mucho menores para el grupo de RE (-5.6%), realizando únicamente dos sesiones semanales de mantenimiento de resistencia, que los descensos del grupo de CE (-11.3%) tras 5 semanas de cesión completa de entrenamiento de resistencia. Al expresar los valores de VO_{2max} en relación a la masa libre de grasa (Fig. 3), los resultados muestran igualmente la efectividad de llevar a cabo un programa de reducción de entrenamiento. Estos hallazgos pueden sugerir la conveniencia de realizar un mantenimiento mínimo de entrenamiento de resistencia durante los periodos de transición con objeto de minimizar las pérdidas de la potencia aeróbica.

En conclusión, nuestros resultados apoyan investigaciones previas mostrando como cortos periodos de cesión de entrenamiento producen mayores descensos de la fuerza y potencia muscular en sujetos de alto nivel con gran experiencia en el entrenamiento de fuerza y resistencia, comparado con la estrategia de reducción de entrenamiento. Además, la potencia muscular parece ser especialmente susceptible a los periodos de desentrenamiento en deportistas de alto nivel, produciendo pérdidas con mayor celeridad que sobre la fuerza máxima. Estos resultados pueden sugerir la necesidad de incorporar programas de reducción de entrenamiento para evitar excesivas pérdidas en el rendimiento neuromuscular y la masa libre de grasa en las fases de recuperación mayores de 2-3 semanas.

Agradecimientos

Queremos agradecer a los profesionales del Centro de Alto Rendimiento y Ciencias del Deporte (CARICD) en Madrid por su excelente apoyo técnico con el instrumental de laboratorio y su asistencia médica a los atletas. También queremos agradecer la dedicación, el esfuerzo y la profesionalidad de los deportistas que tomaron parte en esta investigación.

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ANEXO 3

PUBLICACIONES ORIGINALES

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

Eur J Appl Physiol
DOI 10.1007/s00421-009-1061-2

ORIGINAL ARTICLE

Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle

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Abstract This study was undertaken to analyze changes in selected cardiovascular and neuromuscular variables in a group of elite kayakers across a 12-week periodized cycle of combined strength and endurance training. Eleven world-class level paddlers underwent a battery of tests and were assessed four times during the training cycle (T0, T1, T2, and T3). On each occasion subjects completed an incremental test to exhaustion on the kayak-ergometer to determine maximal oxygen uptake (VO_{2max}), second ventilatory threshold (VT2), peak blood lactate, paddling speed at VO_{2max} (PS_{max}) and at VT2 (PS_{VT2}), stroke rate at VO_{2max} and at VT2, heart rate at VO_{2max} and at VT2. One-repetition maximum (1RM) and mean velocity with 45% 1RM load ($V_{45\%}$) were assessed in the bench press (BP) and prone bench pull (PBP) exercises. Anthropometric measurements (skinfold thicknesses and muscle girths) were also obtained. Training volume and exercise intensity were quantified for each of three training phases (P1, P2, and P3). Significant improvements in VO_{2max} (9.5%), VO_2 at VT2 (9.4%), PS_{max} (6.2%), PS_{VT2} (4.4%), 1RM in BP (4.2%) and PBP (5.3%), $V_{45\%}$ in BP (14.4%) and PBP (10.0%) were observed from T0 to T3. A 12-week periodized strength and endurance program with special emphasis on prioritizing the sequential development of specific physical fitness components in each training phase (i.e. muscle hypertrophy and VT2 in P1, and maximal strength and aerobic power in P2) seems effective for improving both cardiovascular and neuromuscular markers of highly trained top-level athletes.

Keywords Concurrent training · Resistance training · Endurance performance · Canoeing · Exercise testing · Periodization

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Introduction

It is generally accepted by coaches and sport scientists that to maximize physiological adaptations and to avoid overtraining, proper handling of training program variables, including the intensity, frequency and volume of exercise, is required. This is especially important in sports where both endurance and strength need to be simultaneously enhanced to optimize performance (e.g. kayaking). Because strength and endurance training elicit distinct and often divergent adaptive mechanisms (Nader 2006; Sale et al. 1990a), the concurrent development of both fitness components in the same training regime can lead to conflicting neuromuscular adaptations.

This potential conflict has been referred to as an 'interference phenomenon' and it was first described by Hickson (1980), who observed compromised strength development, when strength and endurance training were applied concurrently. However, results of subsequent research have been equivocal, with studies both supporting

(Bell et al. 2000; Craig et al. 1991; Dudley and Djamil 1985; Hennessy and Watson 1994; Kraemer et al. 1995) and questioning (Häkkinen et al. 2003; Hunter et al. 1987; McCarthy et al. 1995, 2002; Sale et al. 1990a) the universal nature of such interference. Several factors such as initial training status of the subjects, exercise mode, volume, intensity and frequency of training, scheduling of sessions, and dependent variable selection may influence the level of interference and explain the contradictory results of these studies (Docherty and Sporer 2000; Leveritt et al. 1999; Sale et al. 1990a). A detailed examination of the existing research on this topic seems to indicate that the volume, especially the frequency of training, may play a critical role in the adaptations consequent to concurrent training (Häkkinen et al. 2003; Izquierdo et al. 2005; McCarthy et al. 2002).

For example, most of the studies have reported concurrent training to be detrimental for strength gains only, when training frequency was higher than 3 days per week (Dudley and Djamil 1985; Hennessy and Watson 1994; Hickson 1980; Hunter et al. 1987; Kraemer et al. 1995). The neuromuscular mechanisms related to power production and explosive strength development seem to be the most affected by the simultaneous training of strength and endurance (Dudley and Djamil 1985; Häkkinen et al. 2003; Hennessy and Watson 1994; Kraemer et al. 1995). By comparison, the majority of current research supports the contention that concurrent training does not alter the ability to adapt to endurance training (Docherty and Sporer 2000; Hickson et al. 1988). Indeed, a number of studies have concluded that the addition of resistance training to ongoing exercise regimens of well-trained endurance athletes is beneficial and results in improved endurance performance (Hickson et al. 1988; Mikkola et al. 2007; Millet et al. 2002). Nevertheless, the question of which is the best way of sequencing sessions targeted at different goals, for the simultaneous development of strength and endurance, remains complex and not satisfactorily solved.

There exists some evidence to support that periodized resistance training programs can result in greater strength gains than non-periodized programs (Fleck 1999; Willoughby 1993). Non-linear or undulating models in which short periods of high volume are alternated with short periods of high intensity training are thought to optimize strength gains (Baker et al. 1994). Unfortunately, there are very few studies in the scientific literature that have explored the effects of periodized training on sports with great demands of both strength and endurance, and even fewer that have done so using elite athletes as subjects. Based on evidence from existing research (Docherty and Sporer 2000; Leveritt et al. 1999, 2000; Sale et al. 1990b; Sporer and Wenger 2003), we chose to structure a periodized program aimed at minimizing the possible interference effects in the simultaneous training of the strength and endurance components of physical fitness. Therefore, it was the purpose of the present study to examine the effects brought about by a 12-week periodized program of combined strength and endurance training on selected neuromuscular and cardiovascular parameters in a group of world-class level kayakers.

Methods

Subjects

Eleven male world-class, flat-water kayak paddlers (all of whom were finalists at the World Championships, including two Olympic gold-medalists) volunteered to take part in this study. Mean (SD) characteristics of participants were as follows: age 26.2 (2.8) years; height 1.83 (0.07) m; body mass 86.2 (5.2) kg; training experience 12.4 (2.1) years, annual paddling volume 4,220 (354) km. Subjects had at least 3 years of familiarization with the testing procedures used in this investigation, and they followed their respective training routines under strict supervision from coaches and sport scientists from the Royal Spanish Canoeing Federation. No physical limitations or musculoskeletal injuries that could affect training were reported. Kayakers underwent a complete medical examination (including ECG) that showed all were in good health condition. The study, which was conducted according to the declaration of Helsinki, was approved by the Bioethics Commission of the University of Seville, and written informed consent was obtained from all subjects prior to participation.

Previous training

Prior to entering the experimental phase of this study, participants had completed a 5-week transition period during which no specific paddling or resistance training was undertaken. Only some recreational physical activities (sport games plus cycling or swimming at low intensities) were performed.

Experimental design and testing sequencing

All subjects followed the same training program during the 12-week duration of the study. Subjects reported to the laboratory on four separate occasions (T0, T1, T2 and T3) throughout the intervention in order to assess the selected cardiovascular, neuromuscular and anthropometric parameters. Testing was completed on three consecutive days: anthropometry and maximal incremental exercise test on the kayak ergometer (day 1), one repetition maximum (1RM) strength (day 2) and power testing (day 3). 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, and all testing sessions were performed at the same time of day (10–12 h) and under similar environmental conditions (20–22 C and 55–65% humidity). In a pilot study, the inter-test reliability for measuring maximal oxygen uptake (VO_{2max}), second ventilatory threshold (VT2), and HR at VO_{2max} (HR_{max}) was assessed by performing two incremental paddling tests to volitional exhaustion, separated by 3 weeks, on a kayak ergometer on 12 elite junior male kayakers, of international competitive level in the 500 m and 1,000 m sprint flat-water events. No significant differences were observed between the 3-week measurements in the endurance variables analyzed. Paddling testing variables showed reliability coefficients ranging from 0.92 to 0.98. The coefficients of variation (CV) for VO_{2max}, VT2, and HR_{max} ranged between 3.2 and 5.1%. The test–retest intraclass correlation coefficients for all strength/power variables used in this study were greater than 0.93 and CV ranged from 0.9 to 2.9%. No control group was used because including such a group while studying elite athletes could be considered highly unethical, since withholding important training stimuli would be detrimental to the athletes' progress (Kraemer 2005).

Anthropometry

Anthropometric measurements included: standing height, body mass, skinfold thicknesses (triceps brachii, subscapular, suprailiac, abdominal, anterior thigh, medial calf, supraspinale and biceps brachii), and muscle girths (chest, forearm, thigh, calf), and were performed by the same experienced investigator in accordance with guidelines from the International Society for the Advancement of Kineanthropometry (ISAK). 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 thicknesses and muscle girths were assessed, respectively, by using a skinfold caliper (accurate to 0.2 mm) and flexible measurement tape (1 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). The first stage was set at a speed of 11.5 km h^{-1}, and the speed increment was 0.5 km h^{-1} each minute. Each kayaker freely adjusted 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 HR telemetry (S610i, Polar Electro Oy, Finland) and recorded every 5 s. Paddlers were encouraged to make a maximal effort and complete as many stages as possible. The test concluded when: (a) the subject voluntarily stopped paddling, or (b) 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. VT2 was determined from gas exchange measurements using the criteria of an increase in both ventilatory equivalents ($V_E\ VO_2^{-1}$ and $V_E\ VCO_2^{-1}$ ratios) 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. VO_{2max} was defined as the average of the two highest single consecutive 15-s VO_2 mean values attained toward the end of the test. The following variables were determined for each paddler: O_2 uptake at VT2 (VO_2 at VT2), VT2 as a percentage of VO_{2max} [VT2 (%VO_{2max})], HR_{max}, HR at VT2 (HR_{VT2}), SR at VO_{2max} (SR_{max}), SR at VT2 (SR_{VT2}), paddling speed at VT2 (PS_{VT2}) and paddling speed at VO_{2max} (PS_{max}). Capillary whole blood samples were taken from each kayaker's earlobe during test recovery (minutes 1, 3, 5, 7 and 10) to determine peak lactate concentration ($[La^-]_{peak}$) using a miniphotometer (LP20, Dr. Lange, France).

Maximal strength and muscle power assessment

1RM was determined in the bench press (BP) and prone bench pull (PBP) using free weights. These were chosen because they are typical resistance training exercises used in the sport of canoeing, and are useful to assess strength and power in the opposing upper-body muscle actions of pushing and pulling. Warm-up consisted of 5 min of stationary cycling at a self-selected easy pace, followed by 5 min of static stretching and upper-body joint mobilization exercises. After a 3-min recovery, a set of six repetitions with the estimated 60% 1RM load, and another set of 2–3 repetitions with the estimated 80% 1RM load for each exercise were performed. Thereafter, each subject performed 3–5 more one-repetition sets with 5-min recovery pauses until his 1RM load could be determined with a precision of 2.5 kg. After two failed attempts at the same load, the test was terminated. The heaviest load that each subject could properly lift, without any external help, was considered to be his 1RM.

On the following day, mean concentric velocity with 45% of the previously determined 1RM load ($V_{45\%}$) was assessed for both exercises. This load was chosen since it has been proved to be very close to the load that maximizes the average mechanical power output for isoinertial upper-body resistance exercises (Cronin and Sleivert 2005; Izquierdo et al. 2002). After an identical warm-up, subjects performed two sets of three repetitions with the 45% 1RM load, using a 5-min recovery pause between sets. Mean velocity was recorded by means of a linear position transducer (MuscleLab, Ergotest Technology, Oslo, Norway). The mean velocity of the three best repetitions for each subject was registered as the $V_{45\%}$. In the BP, subjects lay supine on a flat bench, with their feet resting flat on the floor, and hands placed on the barbell slightly wider (5–7 cm) than shoulder width. After lowering the barbell to the chest, they pushed upwards, at maximum velocity, to the full extension of their elbows. The subjects were not allowed to bounce the bar off their chests or raise the shoulders or trunk off the bench. If this occurred, the trial was rejected and subsequently repeated. In the PBP, paddlers were instructed to lie prone and place their chin on the padded edge of a high bench. The pulling phase began with both elbows in full extension, while the barbell was grasped with hands shoulder-width apart or slightly wider (4–5 cm). The participants were instructed to pull with maximum effort until the barbell struck the underside of the bench, after which it was again lowered to the starting position. In both exercises, subjects' positions on the bench and grip widths were measured so that they could be reproduced on every lift.

Periodized training program

The training cycle was divided into three consecutive training phases. Phases one (P1: from T0 to T1) and two (P2: from T1 to T2) had a duration of 5 weeks, while the final phase (P3: from T2 to T3) lasted only 2 weeks. Two prioritized targets per fitness component (endurance and strength) were chosen to selectively work upon in each phase: P1, VT2 and muscle hypertrophy; P2, maximal aerobic power and maximal strength; and P3, specific kayaking racing pace and maximal power output. Testing was undertaken in the first week of each phase (T0, T1, and T2) and again at the 13th week, right after the completion of the training program (T3). Athletes exercised daily, except one full rest day per week. Strength training sessions were preferentially arranged prior to endurance sessions; when this was not possible, sufficient recovery time (6–8 h) was allowed before undertaking resistance training. Compliance with training requirements was excellent for all participants.

Endurance training

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_{2max}; and zone 3 (Z3), high intensity, between 90% and 100% of VO_{2max}. No higher, supramaximal intensities were used in this study. A description of the characteristics of endurance exercise modes used for training each intensity zone is provided in Table 1. The relative contribution of each of these intensities to the total training volume for each phase was markedly different (Fig. 1). Volume and intensity were carefully controlled and quantified for each training session throughout the full 12-week training cycle. The main variables used for endurance training monitoring were: time spent (hours) and distance covered (km) for volume; and HR and paddling speed for intensity. Distance and speed were registered by means of a GPS receiver (Garmin 201, Garmin Ltd., USA). Total time devoted to endurance training was 52.7 ± 1.9 h in P1, 49.5 ± 1.5 h in P2 and 21.5 ± 0.8 h in P3. Number of endurance training sessions per week ranged from 10 to 15.

Resistance training

Exercise type, loading intensity, number of sets and repetitions as well as rest pauses were different for each training phase (Table 2), and subjects completed three strength training sessions per week. Training to repetition failure was deliberately avoided, and paddlers were constantly encouraged to perform each repetition at maximal concentric velocity, regardless of the load being lifted. Eccentric actions were always performed in a slow controlled manner, lowering the weights in approximately 3 s. In maximal power training sessions (P3), each set was terminated when mean velocity decreased by more than 10% of the best (fastest) repetition's mean concentric velocity. In all strength training sessions, volume was recorded using total load lifted (kg) and number of repetitions completed. Intensity was assessed as percentage of 1RM, and mean concentric velocity in each repetition as measured by the linear position transducer. All training was supervised by professional coaches with several years of experience in the training of kayakers and canoeists. Total strength training volume was 15.6 ± 0.8 h and 2,430 ± 42 repetitions during P1, 13.2 ± 0.7 h and 660 ± 13 repetitions during P2, and 8.4 ± 0.5 h and 520 ± 14 repetitions during P3. The relative contribution of each strength training type to the total training volume in each phase is shown in Fig. 2.

Table 1 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_{2max})
Z1	70–120	1	1–3	20–90	1–3	70–80
Z2	40–90	1–4	1–10	5–20	1–4	80–90
Z3	20–60	2–5	4–8	1–8	2–8	90–100

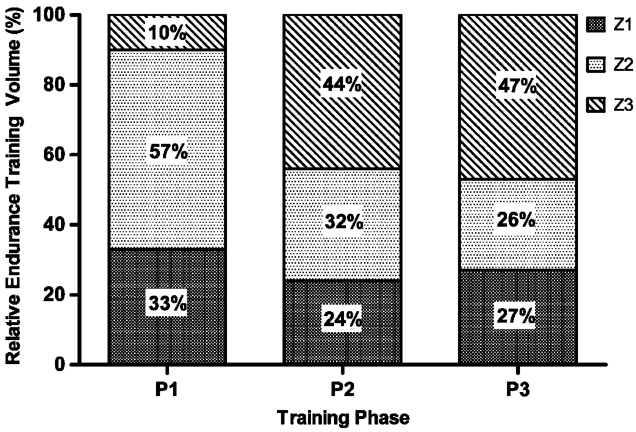

Fig. 1 Relative contribution of each exercise intensity zone to the total endurance training time performed in each phase. Z1 light intensity below VT2, Z2 moderate intensity between VT2 and 90% of VO_{2max}, Z3 high intensity between 90 and 100% of VO_{2max}

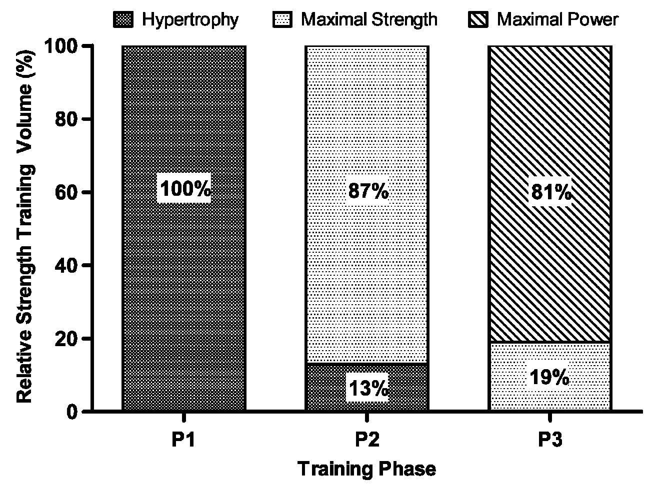

Fig. 2 Relative contribution of each strength training type used in this study to the total training volume in each phase

Statistical analysis

Standard statistical methods were used for the calculation of mean values and standard deviations (SD). The Kolmogorov–Smirnov test was applied to determine the nature of the data distribution. Because a normal distribution was confirmed, repeated measures ANOVA was used to evaluate changes in selected variables over the 12-week training period (T0-T1-T2-T3). Tukey's post hoc test was used to identify the source of any significant differences. Significance was accepted at the $P < 0.05$ level.

Results

Anthropometric changes

Changes in anthropometric measurements are reported in Table 3.

Cardiovascular and endurance performance changes

VO_{2max} increased by 3.5% from T0 to T1 ($P = 0.063$) and by 5.3% from T1 to T2 ($P < 0.01$), while no significant differences in VO_{2max} were observed from T2 to T3. VO_2 at VT2 increased significantly between T0 and T1 (12.4%, $P < 0.01$) but decreased by 4.3% from T1 to T2 ($P < 0.05$). VT2 (%VO_{2max}) significantly increased from T0 to T1 (8.6%, $P < 0.01$), while it decreased 9.0% ($P < 0.01$) when comparing T1 to T2. PS_{max} improved at T1 (2.1%, $P < 0.05$), T2 (2.0%, $P = 0.068$) and T3 (2.0%, $P < 0.05$). No significant differences were observed for the rest of the variables analyzed (HR_{max}, HR_{VT2}, SR_{max}, SR_{VT2}, and $[La^-]_{max}$) (Table 4; Fig. 3).

Strength and power changes

From T0 to T1, 1RM improved significantly (9.7 and 7.7% for BP and PBP, respectively, $P < 0.01$), while $V_{45\%}$

Table 2 Types and characteristics of resistance training

	Exercises	Sets	Repetitions	Load (%1RM)	Rest (min)
Hypertrophy	Bench press, prone bench pull, squat, shoulder press, pull ups	4–5	8–10	70–75	2
Maximal strength	Bench press, prone bench pull, squat	3–4	3–4	85–90	4
Maximal power	Bench press, prone bench pull	4–5	5–8[a]	45	4

[a] Each subject performed the maximum possible number of repetitions until mean concentric velocity dropped by more than 10% of the fastest repetition velocity within that set

Table 3 Changes in anthropometric parameters

	T0	T1	T2	T3
Body mass (kg)	86.0 ± 4.4	88.1 ± 4.8	85.9 ± 4.5	85.6 ± 4.6
Sum of four skinfolds[a] (mm)	35.5 ± 2.9	34.0 ± 2.3	29.0 ± 2.1[#]	34.3 ± 2.3[£]
Sum of eight skinfolds[b] (mm)	67.4 ± 5.1	63.5 ± 4.3	53.5 ± 3.9[#]	63.8 ± 4.5[£]
Thigh girth (cm)	56.4 ± 1.8	58.2 ± 1.6	57.6 ± 1.6	57.3 ± 1.8
Chest girth (cm)	105.2 ± 3.8	109.2 ± 3.9*	107.5 ± 3.4	107.1 ± 3.9
Forearm girth (cm)	28.6 ± 1.1	29.3 ± 1.1	28.9 ± 1.3	28.7 ± 1.1
Calf girth (cm)	36.0 ± 0.7	37.2 ± 0.9	37.0 ± 1.0	37.0 ± 0.9

Data is expressed as mean ± SD

* Significantly different (P ↘ 0.05) when comparing T0 to T1

[#] Significantly different (P ↘ 0.05) when comparing T1 to T2

[£] Significantly different (P ↘ 0.05) when comparing T2 to T3

[a] Triceps brachii, subscapular, supraspinale, abdominal

[b] Four skinfolds ? biceps brachii, suprailiac, anterior thigh, medial calf

Table 4 Changes in selected physiological and performance variables across the 12-week training programme

	T0	T1	T2	T3
PS_{max} (km h^{-1})	14.5 ± 0.3	14.8 ± 0.2*	15.1 ± 0.3	15.4 ± 0.2[£]
PS_{VT2} (km h^{-1})	13.6 ± 0.2	13.9 ± 0.2*	14.1 ± 0.2	14.2 ± 0.3
$[La^-]_{peak}$ (mmol L^{-1})	12.5 ± 3.3	11.8 ± 2.5	12.8 ± 2.2	13.0 ± 2.8
HR_{max} (beats min^{-1})	194 ± 8	188 ± 8	189 ± 10	189 ± 7
HR_{VT2} (beats min^{-1})	175 ± 7	172 ± 7	171 ± 6	172 ± 6
SR_{max} (strokes min^{-1})	104 ± 5	101 ± 9	101 ± 7	103 ± 8
SR_{VT2} (strokes min^{-1})	88 ± 4	84 ± 6	85 ± 5	85 ± 7

Data is expressed as mean ± SD

* Significantly different (P ↘ 0.05) when comparing T0 to T1

[£] Significantly different (P ↘ 0.05) when comparing T2 to T3

Significantly different (P ↘ 0.05) when comparing T0 to T3

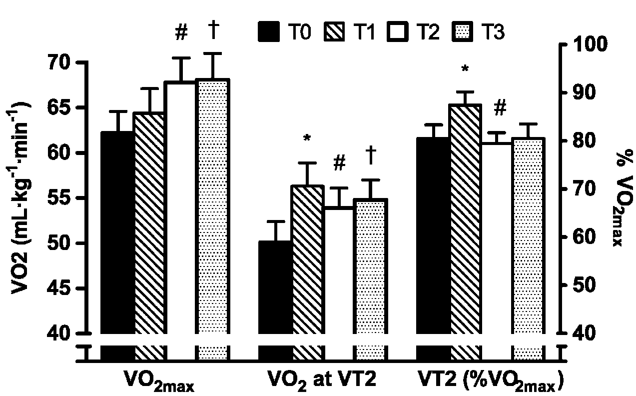

Fig. 3 Changes in VO_{2max} and VT2 across the 12-week training programme. Data is presented as mean ± SD. Significant difference: *P ↘ 0.05 from T0 to T1, [#]P ↘ 0.05 from T1 to T2, [#]P ↘ 0.05 from T1 and T2, P ↘ 0.05 from T0 to T3

remained unchanged in both bench press and prone bench pull exercises. Between T1 and T2, no significant changes were observed in 1RM values, while $V_{45\%}$ improvement was close to statistical significance (5.3%, P = 0.077 for BP and 4.6%, P = 0.082 for PBP). From T2 to T3, 1RM values significantly decreased by 4.6 and 4.5% (P ↘ 0.05) respectively for BP and PBP. Simultaneously, $V_{45\%}$ significantly improved by 11.0% (P ↘ 0.01) in BP and 7.1% (P ↘ 0.01) in PBP. When comparing T0 and T3 values for these variables, significant improvements were found in 1RM values for BP (4.2%, P ↘ 0.05) and PBP (5.3%, P ↘ 0.05). Significant increases were also observed in $V_{45\%}$ for both bench press (14.4%, P ↘ 0.001) and prone bench pull exercises (10%, P ↘ 0.001) (Fig. 4).

Discussion

This study details the changes in selected endurance, anthropometric and strength-related parameters of world-class level kayakers across a 12-week periodized training cycle. The results are important and unique due to the internationally elite level of the athletes, the very high

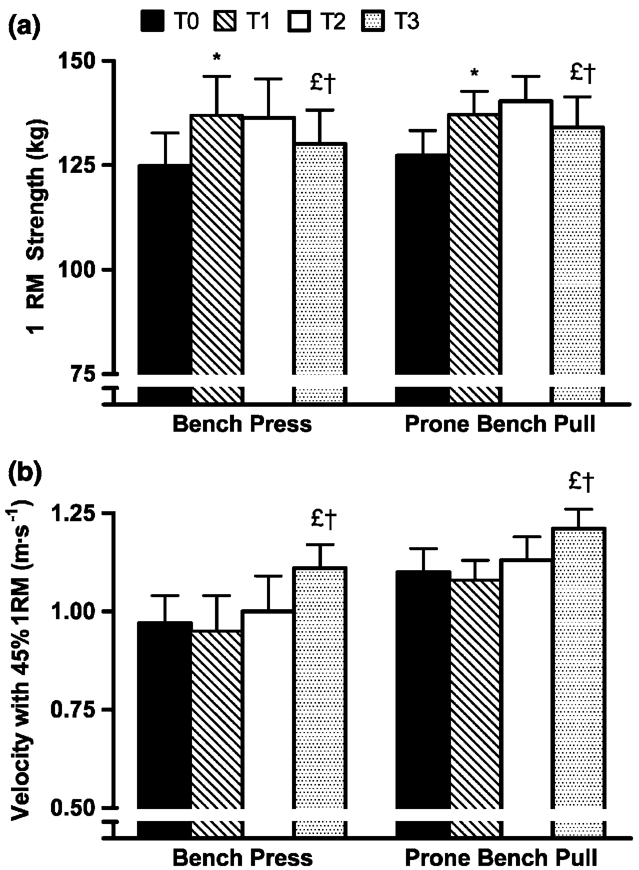

Fig. 4 Changes throughout the 12-week training programme in 1RM strength (a) and mean concentric velocity attained with 45% 1RM load (b) in the bench press and prone bench pull exercises. Data is presented as mean ± SD. Significant difference: *$P < 0.05$ from T0 to T1, £$P < 0.05$ from T2 to T3, $P < 0.05$ from T0 to T3

demands of strength and endurance of their sport discipline as well as the scarcity of this type of study in the literature. The main finding of the present study was that 12-week of periodized training was effective for inducing significant gains in both strength and muscle power as well as endurance performance, showing that it is possible to simultaneously develop these different physical fitness components in a relatively short period of time and at a world-class level of performance.

It has been previously reported that a properly designed and implemented periodization scheme could be the best approach to minimize the potential interference effects in simultaneous strength and endurance training (Baker 2001; Docherty and Sporer 2000). However, little is known about what would be the optimal structure for such periodization during sports requiring both strength and aerobic performance (e.g. Olympic kayaking). According to the model proposed by Docherty and Sporer (2000), we chose to prioritize the fitness components to sequentially develop in each training phase so that potential interferences in the simultaneous training of strength and endurance could be minimized. In particular, the periodized training program used in this study deliberately avoided mixing the specific training objectives of muscle hypertrophy (i.e. strength training objective at P1) and maximal aerobic power (i.e. endurance training objective at P2), because these are thought to be two modes of training that lead to opposite physiological adaptations at the peripheral level that prevent the body from optimally and simultaneously adapting to both of them (Leveritt et al. 1999). Thus, while hypertrophy training would be attempting to increase contractile protein synthesis in the muscle, causing considerable metabolic and hormonal stress at the cellular level, training for aerobic power would require the muscle to increase its oxidative capacity (Docherty and Sporer 2000; Sale et al. 1990a). On the contrary, training at lower aerobic intensities (75–85% VO_{2max}) such as those usually employed to improve the VT2 would induce more centrally mediated adaptations that would be expected to cause much less interference with the method of strength development via muscle hypertrophy (P1). The cited model also predicts less interference when concurrently training for maximal strength/power and aerobic power (P3), because the training stimulus for increasing strength would be mainly directed at the neural system (increased motor unit firing rate and changes in synchronization, recruitment of higher threshold motor units, etc.), not placing high metabolic demands on the muscle. Therefore, it appears that the manipulation of training intensity in each training phase is critical to avoid potential interferences in concurrent training (Docherty and Sporer 2000).

Although the total volume of endurance training was very similar for the first 5-week training phases (52.7 h for P1 and 49.5 h for P2), training intensity was markedly different. While in P1 most of the training volume was devoted to improving the VT2 (57% of total training time in Z2), aerobic power development was favoured in P2 (44% of total training time in Z3). The specificity of training appears to be reflected in the observed cardiovascular changes observed within every training phase. Thus, VO_2 at VT2 was the variable that improved the most in P1 (12.4%), whereas VO_{2max} increased more than any other cardiovascular variable in P2 (5.3%) (Fig. 3). The VO_{2max} mean value of 68.1 mL kg^{-1} min^{-1} reached after the 12-week training intervention is significantly higher than that obtained by other authors with high-level kayakers using similar ergometry testing protocols (i.e. mostly in the 54–60 mL kg^{-1} min^{-1} range) (Bishop et al. 2002; Fry and Morton 1991; Tesch et al. 1983; Van Someren and Oliver 2002). Although the endurance training performed in P1 was not directly focused towards the development of aerobic power (Fig. 1), the almost significant improvement in maximal aerobic power (3.5%) after this training phase (Fig. 3) is probably due to subjects exhibiting a particularly low initial level because of the previous 5-week transition period. As mentioned above, a 5.3% mean improvement in VO_{2max} was obtained in P2, after increasing training time devoted to aerobic power (i.e. from 5.3 to 21.8 h of training in Z3) for these already highly trained athletes. The observed changes in VO_{2max} in only 12 weeks of training (9.5% increase from T0 to T3; Fig. 3) are of similar magnitude to those of 8.0% described in a previous study (Tesch et al. 1976) with international-level kayakers and canoeists after a longer training period (8 months).

Similarly, the specificity of endurance training around the VT2 during P1 (57% of total training time in Z2; Fig. 1) brought about important increases in VO_2 at VT2 (12.4%). In P2, coinciding with an important reduction in training time spent at Z2 (only 32% in this intensity zone), VO_2 values at VT2 significantly decreased by 4.3%; whereas no changes for this variable were observed in P3. After completing the 12-week training cycle, VT2 (%VO_{2max}) was identical to the starting value (80.5%), despite the fact that VO_2 at VT2 was significantly higher (increasing from 50.1 to 54.8 mL kg^{-1} min^{-1} from T0 to T3) (Fig. 3).

Variables closely related to actual kayaking performance, such as PS_{max} and PS_{VT2} increased steadily and similarly throughout the training cycle until reaching an improvement of 6.2 and 4.4% between T0 and T3, respectively (Table 4). It is noteworthy that PS_{max} improved from 15.1 to 15.5 km h^{-1} in the final 2 weeks (P3). The peak blood lactate concentration found after the incremental test to exhaustion on the kayak ergometer (13.0 ± 2.8 mmol L^{-1}) was comparable to the values reported in the literature (Bishop et al. 2002; Tesch et al. 1976, 1983) for similar top-level kayakers (i.e. 13–16 mmol L^{-1}), and occurred at between 5 and 7 min of recovery in all subjects.

The improvements in 1RM values for the bench press exercise (9.7%; Fig. 4), after 5-week of hypertrophy-oriented strength training performed in P1, are comparable to those described for this exercise for moderately strength-trained athletes following similar concurrent training routines in elite junior basketball and soccer players (from 5.2 to 9.6%) (Drinkwater et al. 2005, 2007), or handball players (16%) (Marques and González-Badillo 2006) after 6-week training. This notable increase in maximal strength was obtained even though only very modest levels of hypertrophy were detected in such a short training phase; thus, chest girth was the only variable to significantly increase during this period (Table 3). Unfortunately, MRI or other more sensitive measurements to ascertain the extent of possible hypertrophic changes were not performed in the present study. The greatest improvements in $V_{45\%}$ (11% in BP and 7% in PBP) clearly occurred after P3, where 80% of total resistance-training volume was spent on specifically working with maximal power output loads for upper-body exercises (Fig. 4). During this type of training, the number of repetitions performed in each set was carefully controlled by monitoring the velocity of each repetition and giving immediate feedback to the athlete. The set was stopped when velocity dropped by more than 10% of the fastest repetition mean concentric velocity (Table 2). This made it possible to attain very high power output values in only a few selected repetitions, as already suggested by some authors (Baker and Newton 2007; Izquierdo et al. 2006b; Tidow 1995), as an effective strategy for improving maximal power in highly trained elite athletes. By contrast, maximal dynamic strength decreased considerably in P3 (4.5% in both exercises; Fig. 4) even though 20% of total training time during this phase was of maximal strength type (Fig. 2). This could be explained by the significantly reduced volume and intensity of training during this final tapering phase, perhaps suggesting that high-intensity stimuli are needed in order to maintain maximal strength gains in these highly trained athletes. The 1RM strength values, together with the high VO_{2max} and VO_2 at VT2 found in this study confirm the huge requirements of aerobic power and strength of Olympic sprint kayaking.

Despite the time devoted to endurance training being, on average, more than triple that of resistance training, strength and power markers improved consistently throughout the study. Together with the above-mentioned strategy of prioritizing the development of two target fitness components (i.e. one for strength and another for endurance) in each training phase, the simultaneous improvement in strength and endurance markers observed in the present study may be explained by other factors which we believe helped to reduce conflicting adaptations in the concurrent training of strength and endurance. One important aspect was controlling for training volume and, especially, limiting the frequency of resistance training to only three sessions per week because, as already addressed in the introduction, higher frequencies have proved to compromise strength gains in most concurrent training studies. Research has also highlighted the importance of the order and timing of the aerobic and strength training sessions in order to minimize possible interference effects (Leveritt et al. 1999, 2000; Sale et al. 1990b; Sporer and Wenger 2003). Thus, insufficient recovery between training sessions might limit simultaneous adaptations to strength and endurance training. Residual fatigue from a previous aerobic session could cause a reduction in the quality of subsequent strength training by compromising the ability of the neuromuscular system to rapidly develop force (Leveritt et al. 1999) and/or reducing the absolute volume of strength training that could be performed in such condition (Sale et al. 1990b). Additionally, acute changes in metabolic activity have been reported to be altered by a preceding bout of endurance exercise (Leveritt et al. 2000). Consequently, and following the suggestions outlined by Sporer and Wenger (2003), we decided to schedule strength sessions before endurance sessions or, when not feasible, to separate both types of training sessions by at least 6–8 h to allow for restoration and glycogen repletion.

Two other aspects that we purposely introduced in the design of the training program were the avoidance of strength training sessions leading to muscle failure and the emphasis placed on performing each repetition explosively, with maximal intended concentric velocity. These measures are based on suggestions from previous research (Cronin and Sleivert 2005; Folland et al. 2002; Izquierdo et al. 2006a), and are aimed at maximizing adaptations in the neural component of strength as well as trying to avoid excessive fatigue or mechanical and metabolic strain, which could negatively influence the quality of subsequent training sessions. In the study of Sale et al. (1990b), although same day concurrent resistance and aerobic training induced very similar levels of muscle hypertrophy to those obtained when training strength and endurance on different days, strength gains were significantly higher in the latter case. Therefore, it seems likely that neural adaptations are impaired when combining strength and endurance in the same training session, so that to improve neuromuscular performance and make the most of strength training, sessions must be undertaken in a well-rested, unfatigued state. One may also speculate that similarly to the concurrent strength and endurance program performed in the present study, the shortest events of kayaking, canoeing and rowing could benefit from periodized programs, where emphasis is placed on developing maximal strength and maximal muscle power in certain phases of the training cycle.

A final aspect worth noting has to do with the specific modality of exercise used in strength and endurance training. In the few studies that have used upper-body exercise modalities of resistance and endurance training, there appeared to be no interference in strength development, when concurrent training was compared with strength training alone (Leveritt et al. 1999), whereas the 'interference phenomenon' described by Hickson (1980) was relative to lower body exercise, in which muscle strength is not a limiting factor. It remains to be determined whether there exist differences in concurrent training when training upper or lower-body musculature.

In summary, a 12-week periodized strength and endurance training program with special emphasis on prioritizing the development of specific physical fitness components in each training phase (i.e. muscle hypertrophy and VT2 in P1, and maximal strength and aerobic power in P2) seems effective in improving both cardiovascular and neuromuscular markers of highly trained top-level athletes.

Acknowledgments We thank personnel from the Andalusian High-Performance Sports Medicine Centre 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.

Conflict of interest statement The authors declare that they have no conflict of interest relevant to the content of this manuscript.

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García-Pallarés J, Carrasco L, Díaz A, Sánchez-Medina L (2009) Post-season detraining effects on physiological and performance parameters in top-level kayakers: comparison of two recovery strategies. J Sports Sci and Med 8

Research article

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

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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 Déléris, 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 cardiorrespiratory 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 ± 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 ± 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 ± 540 repetitions for hypertrophy; 44.4 ± 3.2 h, 42 ± 3 sessions, 642 ± 46 sets and 2,600 ± 199 repetitions for maximal strength; and 32.4 ± 1.1 h, 34 ± 2 sessions, 488 ± 29 sets and 2,673 ± 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 (~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 $km \cdot h^{-1}$, subjects completed an incremental paddling test to volitional exhaustion on a kayak ergometer (Dansprint ApS, Denmark; drag resistance coefficent = 35). The first stage was set at a speed of 11.5 $km \cdot h^{-1}$ and the speed increments were 0.5 $km \cdot h^{-1}$ 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 -80ºC 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 $mL \cdot kg^{-1} \cdot min^{-1}$; $p < 0.01$) and -5.6% (from 68.5 ± 3.0 to 64.6 ± 3.1 $mL \cdot kg^{-1} \cdot min^{-1}$; $p < 0.05$) 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

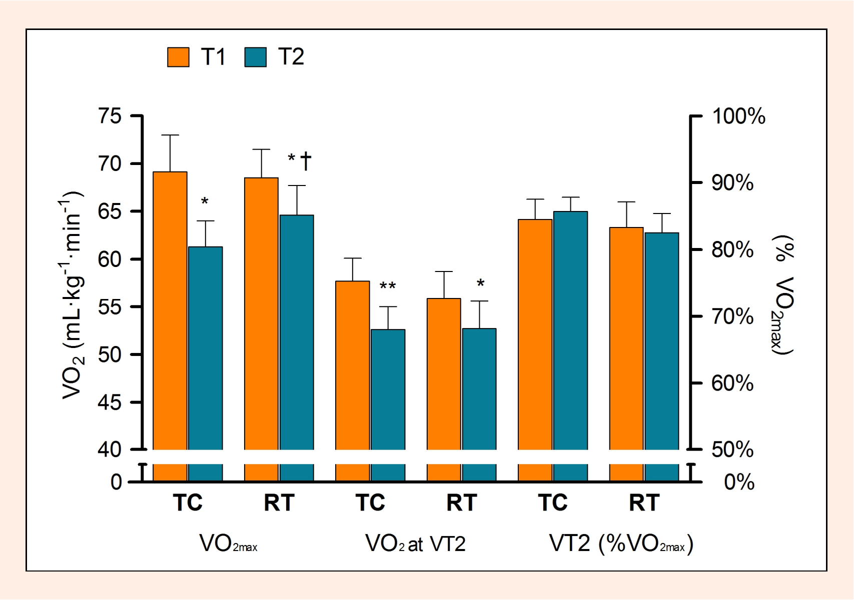

Figure 1. Changes in VO_{2max}, VO_2 at VT2 and VT2 (%VO_{2max}) following a 5-wk period of either training cessation (TC) or reduced training (RT). * $p < 0.05$ compared to T1; ** $p < 0.01$ compared to T1; † $p < 0.05$ compared to TC.

Table 1. Changes in cardiorespiratory and kayaking performance variables. Data are mean (±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.

Pw_{VT2} (-11%, $p < 0.05$) was identical for both TC and RT groups. Values at T1 and T2 for this variable were 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 Déléris, 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 markedy 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. Additionaly, 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 VO_2 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 VO_2 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 VO_2 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 VO_2 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

Table 2. Changes in resting hormones. Data are mean (±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.

following periods of TC in well trained subjects (Coyle et al., 1986; Houmard et al., 1992; Madsen et al., 1993). 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; Neufer 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 Déléris (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. Adittionally, Neufer 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 Hortobágyi 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 (Häkkinen 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 appropiate 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.

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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.

ANEXO 4

INFORMACIÓN DE LAS REVISTAS

European Journal of Applied Physiology

European Journal of Applied Physiology (EJAP) tiene como objetivo promover los avances en la fisiología deportiva. En este sentido EJAP entiende que la fisiología debe considerarse desde una perspectiva global, teniendo en cuenta un gran número disciplinas relacionadas como la biomecánica, la bioquímica, la endocrinología, la ergonomía, la inmunología, control motor, la neurociencia y la nutrición. EJAP acepta artículos que se ocupen de los diferentes niveles de investigación partiendo desde la fisiología molecular, celular y genética, hasta llegar a la fisiología aplicada al deporte de salud o de rendimiento.

Esta revista se encuentra indexada en:

Social Gerontology, Academic OneFile, Academic Search, Biological Abstracts, BIOSIS Previews, CAB Abstracts, CAB International, Chemical Abstracts Service (CAS), CSA/Proquest, Current Abstracts, Current Contents/ Life Sciences, EMBASE, Ergonomics Abstracts, Focus On: Sports Science and Medicine, Gale, Global Health, Google Scholar, Health Reference Center Academic, IBIDS, Index Copernicus, INPHARMA, Journal Citation Reports/Science Edition, OCLC, PASCAL, PubMed/Medline, Science Citation Index, Science Citation Index Expanded (SciSearch), SCOPUS, Sports Discuss, Summon by Serial Solutions y TOC Premier.

Factor de Impacto 2008: 1.931

Posición en el ranking de las revistas de Ciencias del Deporte: 15 de 71

* Journal Citation Reports®, Thomson Reuters.

Journal of Sports Science and Medicine

Journal of Sports Science and Medicine (JSSM) es una revista científica electrónica que pertenece a una organización sin ánimo de lucro, en la que se publican investigaciones y artículos de revisión, junto con estudios de casos en los campos de la medicina deportiva y ciencias del ejercicio. JSSM es una revista electrónica que tiene como principal objetivo ofrecer un fácil acceso a los conocimientos científicos del deporte, empleando para ello medios y métodos actuales. Igualmente esta publicación tiene como misión generar un canal de discusión entre los investigadores que supondrá una oportunidad más para hacer frente a cualquier cuestión o problema de inmediato en el ámbito de las ciencias del deporte.

El Journal of Sports Science and Medicine cubre todos los aspectos de la medicina deportiva y ciencias rehabilitación de lesiones deportivas; todos los aspectos clínicos de ejercicio, salud y deporte, fisiología del ejercicio y la investigación biofísica de rendimiento deportivo, biomecánica deportiva, nutrición deportiva, psicología del deporte; fisioterapia y rehabilitación.

Esta revista se encuentra indexada en:

Sports Science & Medicine, SciSearch, EMBASE, ProQuest (Physical Education Index), EMNursing, COMPENDEX, GEOBASE, SCOPUS, Index Copernicus, SPORTDiscus, DOAJ, J-Gate, GoogleScholar y SPONET

Factor de Impacto 2008: 0.564

Posición en el ranking de las revistas de Ciencias del Deporte: 55 de 71

* Journal Citation Reports®, Thomson Reuters.

Medicine and Science in Sports and Exercise

Medicine & Science in Sports & Exercise (MSSE) es una revista de reconocido prestigio internacional en el ámbito de las ciencias del deporte, cuyo objetivo es publicar investigaciones originales, estudios clínicos y en estudios sobre temas de actualidad en la medicina deportiva y ciencias del ejercicio. Con esta revista líder y multidisciplinar, fisiólogos, fisioterapeutas, médicos de equipo y entrenadores pueden obtener un intercambio de información vital de la ciencia básica y aplicada, la medicina, la educación y campos afines de la salud.

Medicine & Science in Sports & Exercise es la revista oficial de la American College of Sports Medicine

Esta revista se encuentra indexada en:

Sports Science and Medicine, Gale, Global Health, Google Scholar, Health Reference Center Academic, IBIDS, Index Copernicus, INPHARMA, Journal Citation Reports/Science Edition, OCLC, PASCAL, PubMed/Medline, Science Citation Index, Science Citation Index Expanded (SciSearch), SCOPUS, Sports Discuss, Summon by Serial Solutions y TOC Premier. SciSearch, EMBASE, EMNursing, COMPENDEX, GEOBASE, SCOPUS, Index Copernicus, SPORTDiscus, DOAJ, J-Gate, y SPONET. Social Gerontology, Academic OneFile, Academic Search, Biological Abstracts, BIOSIS Previews, CAB Abstracts, CAB International, Chemical Abstracts Service (CAS), CSA/Proquest, Current Abstracts, Current Contents/ Life Sciences, EMBASE, Ergonomics Abstracts, Focus On:

Factor de Impacto 2008: 3.399

Posición en el ranking de las revistas de Ciencias del Deporte: 4 de 71

* Journal Citation Reports®, Thomson Reuters.

ANEXO 5

AUTORIZACIONES

Yo, Luis Sánchez Medina, con DNI 34819236L, coautor de los siguientes artículos:

- 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

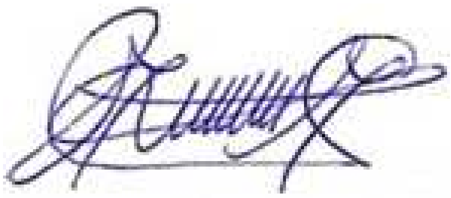
- García-Pallarés J, Carrasco L, Díaz A, Sánchez-Medina L (2009) Post-season detraining effects on physiological and performance parameters in top-level kayakers: comparison of two recovery strategies. J Sports Sci and Med. In press

- García-Pallarés J, Sánchez-Medina L, Pérez CE, Izquierdo-Gabarren M, Izquierdo M (2009) Physiological effects of tapering and detraining in world-class kayakers. Med Sci Sports Exerc. In press

Declaro mi conformidad con la presentación de los citados artículos por parte del doctorando Jesús García Pallarés, y mi compromiso de no presentar estos artículos como parte de otra tesis doctoral, así como que el doctorando es el autor principal de la investigación presentada en los artículos que componen la tesis.

En Murcia, a 23 de noviembre de 2009.

Fdo. Luis Sánchez Medina



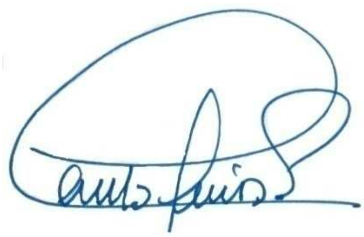
Yo, Carlos Esteban Pérez Caballero, con DNI 20776818K, coautor del siguiente artículo:

- García-Pallarés J, Sánchez-Medina L, Pérez CE, Izquierdo-Gabarren M, Izquierdo M (2009b) Physiological effects of tapering and detraining in world-class kayakers. Med Sci Sports Exerc. In press

Declaro mi conformidad con la presentación de los citados artículos por parte del doctorando Jesús García Pallarés, y mi compromiso de no presentar estos artículos como parte de otra tesis doctoral, así como que el doctorando es el autor principal de la investigación presentada en los artículos que componen la tesis.

En Murcia, a 23 de noviembre de 2009.

Fdo. Carlos Esteban Pérez Caballero



Yo, Mikel Izquierdo Gabarren, con DNI 72459904T, coautor del siguiente artículo:

- García-Pallarés J, Sánchez-Medina L, Pérez CE, Izquierdo-Gabarren M, Izquierdo M (2009b) Physiological effects of tapering and detraining in world-class kayakers. Med Sci Sports Exerc. In press

Declaro mi conformidad con la presentación de los citados artículos por parte del doctorando Jesús García Pallarés, y mi compromiso de no presentar estos artículos como parte de otra tesis doctoral, así como que el doctorando es el autor principal de la investigación presentada en los artículos que componen la tesis.

En Murcia, a 23 de noviembre de 2009.

Fdo. Mikel Izquierdo Gabarren