Anexo I

D. **Antonio Ramos Gordillo** SECRETARIO DEL DEPARTAMENTO DE EDUCACIÓN FÍSICA DE LA UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA,

CERTIFICA,

Que el Consejo de Doctores del Departamento en su sesión de fecha 27 de Marzo de 2007 tomó el acuerdo de dar el consentimiento para su tramitación, a la tesis doctoral titulada "**Efectos del entrenamiento de fuerza sobre la potencia de chut en el fútbol.**" Presentada por el doctorando ***D. Jorge Pérez Gómez*** y dirigida por el ***Dr. José A. López Calbet*****, Dra Cecilia Dorado García y el Dr Javier Chavarren Cabrero.**

Y para que así conste, y a efectos de lo previsto en el Artº 73.2 del Reglamento de Estudios de Doctorado de esta Universidad, firmo la presente en

Las Palmas de Gran Canaria, a 27 de Marzo de dos mil siete.

UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

DEPARTAMENTO DE EDUCACIÓN FÍSICA

PROGRAMA DE DOCTORADO "ACTIVIDAD FÍSICA, SALUD Y RENDIMIENTO DEPORTIVO"

TÍTULO DE LA TESIS

EFECTOS DEL ENTRENAMIENTO DE FUERZA SOBRE LA POTENCIA DE CHUT EN EL FÚTBOL.

Tesis doctoral presentada por: **Jorge Pérez Gómez.**

Dirigida por: **Prof. Dr. José Antonio López Calbet.**
Prof. Dra. Cecilia Dorado García.
Prof. Dr. Javier Chavarren Cabrero.

Los Directores

El doctorando

A mis padres y hermanos.

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Esta tesis esta basada en las siguientes publicaciones:

I. Jorge Perez-Gomez, José A. L. Calbet. **Training to improve vertical jump performance.** Sports Medicine. (enviado).

II. Jens Bangsbo, Magni Mohr, Allan Poulsen, Jorge Perez-Gomez and Peter Krustrup **Training and testing the elite athlete.** J Exerc Sci Fit. Vol 4, nº1, 1-14, 2006.

III. Jorge Perez-Gomez, Germán Vicente-Rodriguez, Ignacio Ara, Hugo Olmedillas, Safira Delgado-Guerra, Javier Chavarren, Juan José Gonzalez-Enriquez, Cecilia Dorado, José A. L. Calbet. **Role of muscle mass on sprint performance.**

IV. Jorge Perez-Gomez, Germán Vicente-Rodriguez, Ignacio Ara, Rafael Arteaga, José A. L. Calbet. **Capacidad de salto en niñas prepúberes que practican gimnasia rítmica.** European Journal of Human Performance 15, 2006.

V. Jorge Perez-Gomez, Germán Vicente-Rodriguez, Ignacio Ara, Javier Chavarren, José A. L. Calbet. **Influence of jumping plyometric training on cycling sprint performance**. European Journal of Human Performance. 11 (41-49), 2004.

VI. Jorge Perez-Gomez, Hugo Olmedillas, Safira Delgado-Guerra, Ignacio Ara Royo, Germán Vicente-Rodriguez, Javier Chavarren, José A. L. Calbet. **Effects of weight lifting combined with plyometric exercises on kicking in football, myosin heavy chain isoforms, and physical performance**. Journal of Sport Science. (enviado).

ABREVIATURAS.

ATP:	Adenosin trifosfato.
AV:	Altura de vuelo.
BM:	Masa corporal, del inglés “*body mass*”.
BMC:	Contenido mineral óseo, del inglés “*bone mineral content*”.
BMD:	Densidad mineral ósea, del inglés “*bone mineral density*”.
cm:	Centímetros.
CMJ:	Salto con contramovimiento, del inglés “*countermovement jump*”.
CON:	Contracción concéntrica.
CSA:	Área de sección transversal del músculo, del inglés “*cross-sectional area*”.
DJ:	Saltos en caída, del inglés “*drop jump*”.
DXA:	Absorciometría fotónica dual de rayos X, del inglés dual “*energy X-ray absorptiometry*”.
EEII:	Extremidades inferiores.
EXC:	Contracción excéntrica.
FIM:	Fuerza isométrica máxima.
Fmaxn:	Fuerza máxima neta.
HQ:	Media sentadilla, del inglés “half squat”.
Hz:	Hertzios.
ILP:	Prensa inclinada, del inglés “*inclined leg press*”.
Ipos:	Impulso mecánico positivo.
Kg:	Kilogramo.
LC:	Flexiones de pierna, del inglés “*leg curl*”.
LDH:	Lactato deshidrogenada.
LE:	Extensiones de pierna, del inglés “*leg extensión*”.
LM:	Masa magra de las extremidades inferiores, del inglés “*lean mass*”.
LT:	Masa magra total.
MHC:	Cadena pesada de miosina, del inglés “*myosin heavy chain*”.
MMB:	Masa magra media de las extremidades superiores.
MMP:	Masa magra media de las extremidades inferiores.
MP:	Potencia media, del inglés “*mean power*”.
ms:	Milisegundos
PC:	Fosfocreatina.
PC:	Ordenador personal, del inglés “*personal computer*”.

PFK: Fosfofructoquinasa.

PI: Impulso mecánico positivo.

Pimax: Potencia instantánea máxima.

PM: Potencia instantánea media.

PP: Potencia pico, del inglés "*peak power*".

Tpimax: Tiempo para alcanzar la potencia instantánea máxima.

RFD: Velocidad de desarrollo de la fuerza, del inglés "*rate of force development*".

RLM: Relación entre la masa muscular relativa de las extremidades inferiores = masa muscular * 100/masa corporal.

RM: Repetición máxima.

s: Segundo/s.

SD: Desviación estándar, del inglés "*standard deviation*".

SEE: Error estándar de la estimación, del inglés "*standard error of estimate*".

SEM: Error estándar de la media, del inglés "*standard error mean*".

SJ: Salto sin contramovimiento, del inglés "*squat jump*".

SSC: Ciclo estiramiento acortamiento, del inglés "*stretch-shortening cycle*".

Tipo II: Fibra de contracción rápida.

Tipo I: Fibra de contracción lenta.

Tfmax: Tiempo necesario para alcanzar el valor máximo de fuerza.

TM: Masa muscular total.

Tvimax: Tiempo en alcanzar la velocidad vertical máxima del centro de masas.

VJH: Altura de vuelo alcanzada en el salto, del inglés "*vertical jump height*".

VD: Velocidad de despegue.

Vimax: Velocidad vertical máxima del centro de masas.

VO_2max: Consumo máximo de oxígeno.

% 1 RM: Porcentaje de la repetición máxima.

%GC: Porcentaje de grasa corporal.

%BF: Porcentaje de masa grasa corporal.

-m: Metro/s.

300-m time: Predicción del tiempo de carrera en 300-m.

30-m time: Predicción del tiempo de carrera en 30-m.

Resumen.

El principal objetivo de esta tesis ha sido analizar el efecto del entrenamiento de fuerza sobre la potencia de chut en el fútbol. Algunos estudios han comunicado una mejora de la potencia de chut con el entrenamiento de fuerza, mientras que otros no han detectado efectos significativos en esta variable. En ninguno de estos estudios se midió la eficacia del programa de entrenamiento sobre otras cualidades físicas que pueden ser importantes en fútbol como, por ejemplo, la velocidad de carrera o la capacidad de salto, tampoco se han comunicado datos acerca de la influencia de estos programas de entrenamiento sobre la masa muscular o tipología muscular. Por lo tanto, en esta tesis hemos pretendido analizar estos factores de forma global en un mismo estudio.

Dado que la masa muscular es uno de los principales factores determinantes de la fuerza y este último incide en la potencia (potencia = fuerza x velocidad), decidimos estudiar la influencia que tiene la masa muscular de las piernas en el rendimiento en pruebas de esprín, otro de los factores que influye en el rendimiento en fútbol. Para tener un espectro mucho más amplio de masas musculares estudiamos a sujetos adultos de ambos sexos (155 estudiantes de Educación Física) y a 26 niñas prepúberes, éstas ultimas dividas en un grupo control y otro de practicantes de gimnasia rítmica. Además se determinó el efecto de 6 semanas de entrenamiento de pliometria sobre el rendimiento en cicloergómetro en 18 estudiantes de Educación Física, asignados aleatoriamente entre el grupo experimental y grupo control. Finalmente, aplicamos un entrenamiento de fuerza combinando pesas y pliometria para ver el efecto sobre la velocidad máxima de extensión de la rodilla.

En todos los sujetos se determinó la masa magra, equivalente a la masa muscular en las extremidades, mediante absorciometría fotónica dual de rayos X (DXA). La velocidad angular máxima de la rodilla durante el chut sobre un balón de fútbol estático se midió con goniómetros telemétricos de alta resolución. Además, se determinó la potencia muscular de las extremidades inferiores mediante saltos verticales sin y con contramovimiento (SJ y CMJ), la velocidad de carrera en 30-m, y se efectuaron tests de capacidad anaeróbica (300-m y test de Wingate), potencia aeróbica (20-m ida y vuelta). La fuerza dinámica e isométrica máxima de las extremidades inferiores fue medida mediante una plataforma de fuerzas. En 25 sujetos se realizaron biopsias musculares en el vasto lateral del cuádriceps.

Se observó que la potencia pico en el Test de Wingate expresada por Kg de masa muscular de las extremidades inferiores fue similar en hombres y mujeres (50 ± 6 y 51 ± 6 W.kg-1, respectivamente, P=0.88). No hubo diferencias entre sexos en la pendiente de la regresión lineal entre la masa muscular de las extremidades inferiores y el pico de potencia o potencia media alcanzada en el Test de Wingate. Sin embargo, cuando la potencia media se expresó por los kilogramos de masa muscular de las extremidades inferiores, los hombres consiguieron un valor un 22% más alto que las mujeres (27 ± 3 y 22 ± 3 W.kg de masa muscular-1, respectivamente, P<0.001). El tiempo de carrera en 30 y 300 metros dividido por la masa muscular de las extremidades inferiores (RLM=LM*100/masa corporal) fue

significativamente menor en los hombres que en las mujeres (169 ± 17 y 234 ± 25 ms. % de masa muscular^{-1}, respectivamente, P<0.001) y (1777 ± 199 y 2720 ± 359 ms. % de masa muscular^{-1}, respectivamente P<0.001). Aunque la pendiente de la regresión lineal entre la masa muscular de las extremidades inferiores y el tiempo en 300 metros no fue significativamente diferente entre sexos, los hombres consiguieron un mayor rendimiento en 300 metros que las mujeres.

Las niñas gimnastas consiguieron una altura de vuelo, velocidad de despegue, impulso mecánico positivo y velocidad vertical máxima del centro de masas mayor en ambos saltos y una potencia instantánea máxima y tiempo de fuerza máxima mayores en el CMJ que las niñas del grupo control (p<0.05).

El grupo que entrenó pliometría durante seis semanas incrementó de manera significativa tanto la potencia pico como la velocidad de pedaleo máxima un 4% (p<0.05), mientras que la mejora en la potencia media fue de un 3% (p=0.09), ninguna de las variables medidas cambió significativamente en el grupo control.

En el último estudio que completa esta tesis observamos que el grupo que entrenó pliometría y pesas mejoró significativamente el pico de velocidad angular de la rodilla durante el chut (14%), el porcentaje de la cadena pesada de miosina (MHC) tipo IIa (8%), el 1 RM de prensa inclinada (61%), extensión de rodilla (20%), media sentadilla (45%), y el rendimiento en el salto vertical, respecto al grupo control (p < 0.05).

Por ello, concluimos que la masa muscular de las extremidades inferiores es el principal factor que explica las diferencias entre sexos en la capacidad de esprín en cicloergómetro, en ambos sexos la potencia pico alcanza un valor medio de 50 vatios por kilogramo de músculo. La masa muscular de las extremidades inferiores guarda relación con el rendimiento en esprín de carrera, aunque sólo explica una parte de la variabilidad entre sujetos. Seis semanas de entrenamiento pliométrico permiten mejorar el rendimiento en esprín en cicloergómetro. El entrenamiento de fuerza combinando levantamiento de pesas y ejercicios pliométricos permite aumentar la velocidad angular máxima de la rodilla durante el chut en el fútbol, así como la capacidad de salto vertical, la fuerza máxima y la proporción de la cadena pesada de miosina tipo IIa, sin embargo, no mejora la velocidad de carrera en 30 metros.

Introducción general

Varios son los factores que influyen en el rendimiento en el fútbol, la potencia con la que un futbolista es capaz de chutar a puerta, el salto vertical, la fuerza máxima, la capacidad de esprín, etc. A pesar de los numerosos y variados estudios publicados sobre futbolistas no existe ninguno en la literatura científica que englobe estos factores en un solo estudio. Se ha observado que el puesto final en la tabla clasificatoria guarda relación con la capacidad de salto de los futbolistas, que una mejora en la resistencia aeróbica permite mejorar el rendimiento en el fútbol ya que aumenta el número de esprines, la distancia recorrida, la intensidad de trabajo y el número de intervenciones con el balón durante un partido. También se ha visto que existe una alta correlación entre la fuerza máxima en sentadilla con el rendimiento en esprín y la altura de salto vertical en futbolistas de elite. Respecto al chut hay estudios que observaron una mejoría con el entrenamiento de fuerza y otros no, en ninguno de estos estudios sobre el chut se ha medido la eficacia del programa de entrenamiento sobre otras cualidades físicas que pueden ser importantes en fútbol como, por ejemplo, la velocidad de carrera o la capacidad de salto, tampoco se han comunicado datos acerca de la influencia de estos programas de entrenamiento sobre la masa muscular o tipología muscular. Por lo tanto, en esta tesis hemos pretendido analizar estos factores de forma global en un mismo estudio.

Para comprobar si es posible mejorar la potencia de chut en el fútbol, realizamos una revisión bibliográfica sobre los métodos de entrenamiento de fuerza para mejorar la capacidad de salto vertical, factor que se ha comunicado que correlaciona con la potencia de chut (artículo I). También efectuamos una segunda revisión bibliográfica para tener un mejor conocimiento basado en la evidencia científica sobre las características de los entrenamientos de los futbolistas de elite, en la que aportamos datos sobre la preparación del equipo nacional de fútbol de Dinamarca para la Eurocopa de Fútbol de 2004 (artículo II). Dado que la masa muscular es uno de los principales factores determinantes de la fuerza y este último incide en la potencia (potencia = fuerza x velocidad), decidimos estudiar la influencia que tiene la masa muscular de las piernas en el rendimiento en pruebas de esprín, otros de los factores que influye en el rendimiento en fútbol. Para tener un espectro mucho más amplio de masas musculares estudiamos a sujetos adultos de ambos sexos (155 estudiantes de Educación Física) (artículo III) y a 26 niñas prepúberes, éstas ultimas dividas en un grupo control y otro de practicantes de gimnasia rítmica (artículo IV). En el quinto artículo de esta tesis presentamos un estudio acerca de los efectos de un programa de entrenamiento de pliometria, de corta duración, que podría ser implementado fácilmente durante la pretemporada en futbolistas, sobre el rendimiento en pruebas de esprín (artículo V). En este último estudio participaron 18 estudiantes de Educación Física, asignados aleatoriamente a un grupo experimental y a un grupo control. Finalmente, aplicamos un entrenamiento de fuerza combinando pesas y pliometria para ver el efecto sobre el rendimiento en la potencia de chut. En este último trabajo intervinieron 37 estudiantes de Educación Física, que fueron divididos en dos grupos: un grupo control (21 sujetos) y un grupo experimental (16 sujetos). A 25 sujetos se les realizó una biopsia muscular del vasto lateral del músculo cuádriceps y se determinó el efecto del programa de entrenamiento aplicado sobre la expresión de isoformas de las cadenas pesadas de la molécula de miosina (MHC), ya que los cambios en la expresión de MHC puede repercutir tanto en la fuerza muscular como en la velocidad máxima de contracción, y por lo tanto, en la potencia de chut (artículo VI).

Los resultados reflejados en esta tesis amplían el conocimiento actual acerca de los efectos de distintos modelos de entrenamiento sobre la estructura y la función del músculo esquelético humano, así como sobre la importancia que tiene la masa muscular para el desarrollo de potencia muscular. Algunos de estos resultados serán sin duda de interés para el entrenamiento de los futbolistas con el objetivo de mejorar su potencia de chut y otras cualidades que inciden en su rendimiento deportivo.

ÍNDICE.

1. INTRODUCCIÓN.

1.1 ANTECEDENTES.

El entrenamiento de fuerza ha sido estudiado con el objeto de mejorar tanto el bienestar físico (Kilbreath *y col.*, 2006; Olson *y col.*, 2006; Reeves *y col.*, 2006; Suominen, 2006) como el rendimiento en diversas actividades físicas o modalidades deportivas (Cronin y Sleivert, 2005; Henwood y Taaffe, 2005; Silvestre *y col.*, 2006). Se considera que las adaptaciones en fuerza son debidas a estímulos mecánicos originados por la cinética de los ejercicios utilizados y sus interacciones con otros factores como el hormonal y metabólico (Crewther *y col.*, 2005). En el ámbito de la salud la mejora de los niveles de fuerza permite disminuir el riesgo de sufrir caídas y por consiguiente fracturas óseas en personas mayores (Schlicht *y col.*, 2001; Kraemer *y col.*, 2002a; DiBrezzo *y col.*, 2005), además mejorar la fuerza permite alcanzar mejores resultados en diversos test físicos (Vandewalle *y col.*, 1987b; Rodacki *y col.*, 2002; Ugarkovic *y col.*, 2002).

La potencia muscular es una de las manifestaciones de fuerza fundamentales para conseguir un mayor rendimiento deportivo (Wilson *y col.*, 1993; Kawamori y Haff, 2004). La potencia se puede definir como la cantidad de trabajo producida por unidad de tiempo o el producto de la fuerza por la velocidad (Cronin y Sleivert, 2005). El salto vertical es una actividad física que depende en gran medida la potencia muscular de las extremidades inferiores (Bosco *y col.*, 1983; Driss *y col.*, 1998), por lo que muchos estudios han aplicado programas muy diversos de entrenamiento de fuerza con el objetivo de ver cual era el más óptimo para mejorar su rendimiento entre los que destacan los ejercicios pliométricos (Bobbert *y col.*, 1987; Hakkinen, 1993; Hewett *y col.*, 1996; Potteiger *y col.*, 1999; Diallo *y col.*, 2001; Matavulj *y col.*, 2001), el entrenamiento con pesas (Schmidtbleicher y Haralambie, 1981; Colliander y Tesch, 1991; Baker *y col.*, 1994; Robinson *y col.*, 1995; Newton *y col.*, 1999; Harris *y col.*, 2000), la electroestimulación (Eriksson *y col.*, 1981; Martin *y col.*, 1993; Maffiuletti *y col.*, 2000; Maffiuletti *y col.*, 2002b) y el tratamiento vibratorio del cuerpo entero (Seidel, 1988; Bosco *y col.*, 1999; Torvinen *y col.*, 2002a; Torvinen *y col.*, 2002b). Llegando incluso a combinar estos métodos de entrenamiento (Fowler *y col.*, 1995; Holcomb *y col.*, 1996; Lyttle *y col.*, 1996; Maffiuletti *y col.*, 2002a) ya que una mejora en el salto vertical se asocia a un mejor rendimiento deportivo (Bobbert, 1990; Cometti *y col.*, 2001; Rodacki *y col.* , 2002; Ugarkovic *y col.* , 2002).

Sin embargo, todavía no se conoce con certeza cual es el entrenamiento óptimo de fuerza para alcanzar el máximo rendimiento (Cronin y Sleivert, 2005). De hecho, se aplican diferentes tipos de entrenamiento de fuerza de manera aislada o combinada (Fowler *y col.* , 1995; Holcomb *y col.* , 1996; Lyttle *y col.* , 1996; Maffiuletti *y col.* , 2002a). Menos se sabe todavía acerca de cómo combinar distintos modelos de entrenamiento de fuerza con el objetivo de mejorar el rendimiento en acciones deportivas específicas, como es el caso del chut en fútbol (Lees y Nolan, 1998; Bangsbo, 1994; Lees y Nolan, 1998), que será objeto de estudio en esta tesis. En general, la mejora en la fuerza muscular de las extremidades inferiores ha demostrado ser eficaz para aumentar la potencia de chut (De Proft *y col.*, 1988; Jelusic *y col.*, 1992; Dutta y Subramanium, 2002; Manolopoulos *y col.*, 2004).

1.2 ENTRENAMIENTO DE FUERZA.

El entrenamiento de fuerza constituye un estímulo fundamental para producir cambios en la fuerza y potencia muscular. Varias han sido las variables utilizadas para diseñar programas de entrenamiento de fuerza entre las que destacan: la carga, el volumen, las recuperaciones, la frecuencia, la velocidad de ejecución y el tipo de acción muscular.

1.2.1 Intensidad de entrenamiento.

La intensidad del entrenamiento es una de las variables más importantes a tener en cuenta en el entrenamiento de fuerza (McDonagh y Davies, 1984). Viene determinada por la cantidad de peso a mover durante la realización del ejercicio, generalmente se determina como el porcentaje de la repetición máxima (% 1RM). Aunque también se puede expresar como número máximo de repeticiones que se pueden realizar con una resistencia (o peso) determinado cuando el ejercicio se realiza con la técnica adecuada. Se ha especulado que las unidades motoras con un mayor umbral de estimulación pueden ser reclutadas preferentemente con cargas supramáximas, lo que podría ser ideal para el desarrollo de la fuerza máxima y la potencia (Behm, 1995).

1.2.2 Volumen de entrenamiento.

El volumen indica la cantidad total de trabajo realizado en una sesión de entrenamiento, y se calcula a partir del peso total desplazado, o trabajo total, si es posible medirlo (Tan, 1999). El volumen se suele definir como el total de las repeticiones realizadas, las cuales se calculan multiplicando las series por las repeticiones (Baker *y col.* , 1994); otra manera de interpretar el volumen de entrenamiento es multiplicando el número total de repeticiones realizadas en una sesión por el peso utilizado (Kraemer *y col.* , 2002a). Las ganancias en fuerza parecen ser mayores cuando el programa de entrenamiento implica un mayor volumen de trabajo respecto a otro con menor volumen de trabajo (Kramer *y col.*, 1997; Borst *y col.*, 2001; Marx *y col.*, 2001; Schlumberger *y col.*, 2001). Parece ser que durante el desarrollo de una mayor cantidad de trabajo los músculos están sometidos a un mayor estrés mecánico lo que lleva a mayores adaptaciones musculares (Crewther *y col.* , 2005). Un incremento en el trabajo mecánico también produce una mayor respuesta tanto hormonal como metabólica (Kraemer *y col.*, 1990; Kraemer *y col.*, 1991; Kraemer *y col.*, 1993; Mulligan *y col.*, 1996), las cuales son importantes para que se produzca un crecimiento muscular (Jones, 1992). Sin embargo, también se ha observado que un volumen moderado en levantadores de peso es más efectivo que intensidades más altas (Gonzalez-Badillo y col., 2006; Gonzalez-Badillo JJ y col., 2005).

1.2.3 Recuperaciones.

Las recuperaciones representan el tiempo de descanso entre series y ejercicios dentro de una misma sesión de entrenamiento. La duración de la recuperación afecta al sistema hormonal (Kraemer *y col.* , 1990; Kraemer *y col.* , 1991; Kraemer *y col.* , 1993), cardiovascular (Fleck, 1988) y metabólico (Kraemer *y col.*, 1987), por lo tanto, no deberían pasarse por alto a la hora de prescribir ejercicios de fuerza (Fleck y Kraemer, 1988), además teniendo en cuenta que dicha duración determina no sólo la recuperación de las fuentes de energía de adenosin trifosfato (ATP) y fosfocreatina (PC) (Kraemer *y col.*, 2002b) sino también el incremento de lactato en sangre (Kraemer *y col.* , 1987; Kraemer *y col.* , 1990). Se considera que la resíntesis de ATP y PC suele completarse entre 3-5 minutos (Harris *y col.*, 1976; Kraemer *y col.* , 2002b).

La duración del periodo de recuperación suele depender del objetivo del entrenamiento, de la carga levantada y del nivel de entrenamiento de los sujetos.

1.2.4 Frecuencia de entrenamiento.

La frecuencia de entrenamiento hace referencia al número de sesiones completadas en un periodo de tiempo determinado que normalmente es de una semana, depende de varios factores entre los que destacan el volumen de entrenamiento, la intensidad, los ejercicios seleccionados, el nivel de condición física de los sujetos, la capacidad de recuperación (Kraemer *y col.* , 2002a). En sujetos inexpertos la frecuencia suele ser de 2-3 días por semana (Coyle *y col.*, 1981; Braith *y col.*, 1989; Dudley *y col.*, 1991; Hickson *y col.*, 1994; Carroll *y col.*, 1998; Tarpenning *y col.*, 2001; Campos *y col.*, 2002; Paulsen *y col.*, 2003), no obstante, es importante que la frecuencia de entrenamiento sea suficientemente amplia como para permitir que la musculatura se recupere con el objeto de evitar el sobreentrenamiento (Hass *y col.*, 2001). En sujetos altamente entrenados la frecuencia puede oscilar entre 5-7 días por semana (Kraemer *y col.* , 1987).

1.2.5 Velocidad de ejecución.

La velocidad de contracción muscular usada en acciones musculares dinámicas es un factor crítico en las adaptaciones inducidas por el ejercicio a nivel neural (Eloranta y Komi, 1980; Hakkinen *y col.*, 1985a; Hakkinen *y col.*, 1985b), hipertrófica (Housh *y col.*, 1992) y metabólica (Ballor *y col.*, 1987) en los ejercicios de fuerza. Para sujetos inexpertos se recomienda una velocidad de ejecución lenta o moderada, mayor o igual a 1-2 segundos tanto para la fase concéntrica (CON) como excéntrica (EXC). Para sujetos con un nivel de entrenamiento intermedio, se recomienda una velocidad moderada de 1-2 segundos. Mientras que para sujetos con nivel alto de entrenamiento se recomienda utilizar velocidades continuas de lentas a rápidas para alcanzar máximas mejoras en la fuerza (Kraemer *y col.* , 2002b). Hay que destacar que una técnica adecuada debe estar presente en todas las velocidades de ejecución de los ejercicios para reducir el riesgo de lesión (Kraemer *y col.* , 2002b).

1.2.6 Tipo de acción muscular.

La mayoría de los programas de entrenamiento de fuerza incluyen movimientos dinámicos concéntricos (CON), acortamiento muscular, y excéntricos (EXC), alargamiento muscular, mientras que la contracción muscular isométrica, sin acortamiento o alargamiento muscular, parece ser menos utilizada (Kraemer *y col.* , 2002b). Varios estudios han demostrado que la fuerza muscular dinámica y los cambios morfológicos en el músculo son mayores cuando ambas contracciones CON y EXC son empleadas en los ejercicios de fuerza (Colliander y Tesch, 1990; Dudley *y col.* , 1991; O'Hagan *y col.*, 1995). Cabe destacar que las acciones musculares excéntricas permiten generar más fuerza (Komi *y col.*, 1987; Jones, 1992), son más eficientes a nivel neuromuscular (Eloranta y Komi, 1980; Komi *y col.* , 1987), suponen un menor coste metabólico (Dudley *y col.* , 1991; Smith y Rutherford, 1995), ocasionan mayor daño muscular (Ebbeling y Clarkson, 1989) y pueden ocasionar también mayor hipertrofia muscular (Hather *y col.*, 1991) que las acciones musculares concéntricas. Sin embargo, existen alguna controversia, ya que algunos estudios han observado que el entrenamiento concéntrico es tan efectivo en mejorar la fuerza y provocar hipertrofia como el excéntrico (Jones y Rutherford, 1987; Mayhew *y col.*, 1995; Smith y Rutherford, 1995). Las contracciones concéntricas se asocian a una mayor respuesta hormonal cuando se comparan a una contracción excéntrica efectuada con la misma carga absoluta (Durand *y col.*, 2003).

1.3 ENTRENAMIENTO DE FUERZA MÁXIMA.

Hasta hoy las mejoras en la fuerza máxima se atribuyen a un incremento en la morfología del músculo (área de sección transversal (CSA) y/o a una mejora en la coordinación a nivel neural (reclutamiento de unidades motoras, frecuencia de disparo, sincronización y actividad refleja). Algunas cargas parecen más adecuadas para producir mejoras tanto a nivel neural como estructural, no obstante, hemos de tener en cuenta que existen estudios en los que se ha observado que utilizando cargas más bajas (< 45% 1 RM) también se ha conseguido tanto hipertrofia muscular como mejoras en la fuerza máxima (Lyttle *y col.* , 1996; Moss *y col.*, 1997; Harris *y col.* , 2000), aunque éstas diferencias podrían ser debidas al nivel de entrenamiento de los sujetos (Crewther *y col.* , 2005).

1.3.1 Adaptaciones neurales.

Los programas utilizados para aumentar la fuerza a través de una mejora en la coordinación neural se representan generalmente con intensidades altas del 85-100% del 1 RM con pocas repeticiones (1-6) por serie y periodos de recuperación largos (3-5 minutos) (Kraemer *y col.* , 2002a; Bird *y col.*, 2005; Crewther *y col.* , 2005; Peterson *y col.*, 2005). Las cargas altas implican una mayor producción de fuerza, éstas a su vez están asociadas a un mayor reclutamiento de unidades motoras acorde al principio del tamaño (McDonagh y Davies, 1984; Behm, 1995). Se sabe que las cargas altas se caracterizan por velocidad de ejecución más lentas, esto implica un mayor tiempo de contracción muscular o por tanto el músculo activado está sometido a tensión también durante más tiempo (Crewther *y col.* , 2005). Una tensión muy elevada podría resultar en la activación de señales inhibidoras a través de la activación de mecanismos reflejos (órganos del tendón de Golgi) que podrían limitar la capacidad para generar fuerza por un lado, pero por otro podrían mejorar la sincronización en la velocidad de disparo de las unidades motoras (Komi, 1986; Hakkinen, 1989). Además se considera que una gran fuerza es importante para remodelar el tejido muscular en cuanto a la síntesis y degradación de proteínas (Lieber y Friden, 1993; Goldspink, 1999; Fowles *y col.*, 2000). Por lo tanto, teniendo en cuenta la importancia que tiene una producción elevada de tensión, la utilización de cargas altas en los entrenamientos parece ser adecuada para estimular el desarrollo de la fuerza máxima (Crewther *y col.* , 2005).

Está generalmente aceptado que las adaptaciones neurales juegan un papel importante en la ganancia de fuerza muscular. Una de las razones que llevan a ello es observar que se puede producir un incremento en la fuerza muscular sin que haya una notable hipertrofia muscular. La electromiografía de superficie ha revelado que la ganancia inicial de fuerza durante las primeras semanas de entrenamiento están asociadas a un incremento en la amplitud de la actividad electromiográfica. Esto ha sido interpretado como un aumento en la activación neural (Gabriel *y col.*, 2006).

1.3.2. Adaptaciones estructurales (hipertrofia muscular).

En líneas generales las cargas utilizadas para producir un mayor cambio en el área de sección transversal del músculo se caracterizan por cargas próximas al 70% de 1 RM con varias repeticiones (8-12) y recuperaciones cortas (1 minuto) (McDonagh y Davies, 1984; Kraemer *y col.* , 2002a; Crewther *y col.* , 2005). Varios estudios han demostrado que el entrenamiento de fuerza provoca hipertrofia muscular (Goldberg *y col.*, 1975; Jackson *y col.*, 1990; Staron *y col.*, 1991; McCall *y col.*, 1996; Kadi *y col.*, 1999; Tarpenning *y col.* , 2001; Shoepe *y col.*, 2003). La hipertrofia muscular requiere un aumento de las proteínas musculares (Booth y Thomason, 1991). Se ha observado un incremento en la síntesis de proteínas con el entrenamiento de fuerza (Phillips *y col.*, 1997; Phillips, 2000) permaneciendo elevado el pico de síntesis de proteínas aproximadamente durante las 24 horas después del ejercicio (Gibala *y col.*, 1995; MacDougall *y col.*, 1995; Phillips *y col.* , 1997; Hernandez *y col.*, 2000). Las fibras rápidas tipo II presentan mayor facilidad para hipertrofiarse en respuesta al entrenamiento de fuerza que las fibras tipo I (Alway *y col.*, 1989; Hather *y col.* , 1991; McCall *y col.* , 1996; Tarpenning *y col.* , 2001).

1.4 ENTRENAMIENTO DE POTENCIA MUSCULAR.

Cargas ligeras de 30-45% de 1 RM con movimientos explosivos realizando poco volumen y tiempos de recuperación moderados (2-3 minutos) han sido las características recomendadas para mejorar la potencia muscular, basándose en el hecho de que estas cargas son efectivas para mejorar la producción de potencia mecánica en movimientos que requieren explosividad (Wilson *y col.* , 1993; Morrissey *y col.*, 1995; Lyttle *y col.* , 1996; Crewther *y col.* , 2005). Estas cargas bajas permiten que se alcance una mayor aceleración y velocidad en el movimiento y se ha defendido que el entrenamiento con cargas bajas y alta velocidad de ejecución lleva a una mejor transferencia hacia el gesto deportivo en aquellos deportes que requieren explosividad. No obstante, varios estudios han observado que la utilización de cargas más altas (> 50% 1 RM) son igualmente efectivas que las cargas bajas para mejorar la potencia muscular (Hoff y Almasbackk, 1995; McBride *y col.*, 2002; Siegel *y col.*, 2002). Esto puede sugerir que existe una banda más ancha de cargas que puede ser óptima para la máxima producción de potencia mecánica del músculo (Kraemer *y col.* , 2002a). De hecho se ha observado que sujetos más fuertes alcanzan el pico de potencia a porcentajes más altos de sus respectivos 1RM que los sujetos más débiles (Stone *y col.*, 2003), lo que podría sugerir que la habilidad para producir potencia es transitoria y afectada por los cambios en la fuerza máxima (Crewther *y col.* , 2005). Otra de la razones podría ser que las cargas altas permiten mejorar el componente de fuerza mientras que las bajas la velocidad de desarrollo de la fuerza, ya que la potencia muscular depende no sólo de la fuerza muscular sino también de la velocidad de contracción (Sipila *y col.*, 2004). En este sentido, el uso de cargas ligeras o bajas permite alcanzar velocidades de contracción mayores (Behm, 1995), también permite mejorar la coordinación intermuscular en el movimiento funcional (Young y Bilby, 1993). Otro de los efectos del entrenamiento asociado a cargas bajas y alta velocidad de ejecución podría estar relacionado con factores neurales como, por ejemplo, inhibición del reflejo tendinoso inverso de Golgi, facilitación de los husos musculares, y cambios en la coactivación de los antagonistas y sinergistas implicados en el movimiento (Newton y Kraemer, 1994; Behm, 1995).

En cualquier caso, para optimizar la ganancia de potencia muscular, parece racional entrenar la potencia a velocidades de contracción muscular similares a las específicas en el deporte en concreto (Crewther *y col.* , 2005).

Hasta que existan nuevos estudios que puedan clarificar cual es el procedimiento óptimo para mejorar la potencia muscular parece ser que la manera más adecuada y segura para conseguir mejorar la potencia es aquella que combina una estrategia de entrenamiento mixta en la que se usan cargas altas y bajas (Cronin y Sleivert, 2005). Esto se ha intentado conseguir utilizando diversos modelos de entrenamiento como por ejemplo los ejercicios basados en el ciclo estiramiento acortamiento y el entrenamiento basado en movimientos balísticos.

1.4.1 Ciclo estiramiento acortamiento (SSC).

El SSC es una manera frecuente de activación de la musculatura que ocurre cuando una acción concéntrica esta precedida por una contracción excéntrica. Es un movimiento realizado con el objetivo de mejorar la potencia muscular. Tres son los mecanismos por los cuales se intenta explicar como el SSC permite una mayor producción de fuerza a una velocidad de movimiento más rápida: potenciación mecánica (Asmussen y Bonde-Petersen, 1974; Komi y Bosco, 1978; Bosco *y col.*, 1982; Bobbert, 2001), mayor tiempo de aplicación de fuerza (Bobbert *y col.*, 1986; Bobbert y van Zandwijk, 1999) y potenciación postetánica (Ranke, 1865).

1.4.2 Entrenamiento balístico.

El término balístico hace referencia a un técnica de entrenamiento en la cual la carga utilizada, bien una barra o el peso corporal, es proyectado o dejado al final de la fase concéntrica de manera explosiva con el objetivo de mejorar la potencia muscular. Varios estudios han utilizado esta técnica (Newton y Kraemer, 1994; Newton *y col.* , 1999; Cronin *y col.*, 2001; Cronin *y col.*, 2003). La manera en la que los ejercicios son realizados es también importante. En comparación con las máquinas fijas, la utilización de pesos que pueden ser proyectados libremente o la utilización del peso corporal para saltar tienen como ventaja que permiten un mayor grado de libertad de movimiento, una mayor variación en el entrenamiento, también permiten una mejor transferencia hacia el rendimiento funcional. (Crewther *y col.* , 2005)

1.3 DIFERENCIAS ENTRE SEXOS.

Las diferencias entre hombres y mujeres en el rendimiento en pruebas de carrera ha suscitado gran interés en los últimos años (Cheuvront *y col.*, 2005).

1.5.1 Rendimiento en esprín de carrera.

El éxito en pruebas de esprín esta determinado por la fuerza muscular (Cheuvront *y col.* , 2005). La masa muscular es uno de los principales factores que determina la producción de fuerza muscular (Sperling, 1980; Young *y col.*, 1984; Frontera *y col.*, 1991). Por ello, una de las razones que podría explicar las diferencias entre sexos en el rendimiento en pruebas de carrera y ciclismo puede ser debida a las diferencias existentes en la cantidad de masa muscular entre sexos.

La velocidad de esprín en carrera se define básicamente como el producto de la longitud de zancada por la frecuencia de zancada. Las diferencias en el rendimiento en pruebas de esprín de 100 metros entre hombres y mujeres es de un 7% a favor de los hombres (Cheuvront *y col.* , 2005). Por lo tanto, los hombres deberían tener una mayor longitud de zancada, frecuencia de zancada o ambas cosas respecto a las mujeres. Sin embargo, se ha observado que la frecuencia de zancada es similar en hombres y mujeres, tanto en los más rápidos como en los más lentos. No obstante, se ha constatado que los corredores más rápidos aplican mayor fuerza contra el suelo (Weyand *y col.*, 2000) lo que les proporciona un mayor impulso mecánico que les permite desarrollar zancadas más largas (Weyand *y col.* , 2000). Esta capacidad superior para generar impulso mecánico en cada apoyo se ha relacionado con una mayor proporción de fibras musculares rápidas, que son más potentes (Weyand *y col.* , 2000).

No obstante, la distribución del tipo de fibras es similar en hombres y mujeres, practicantes de diversas modalidades deportivas (Costill *y col.*, 1976; Schantz *y col.*, 1983; Sale *y col.*, 1987; Alway *y col.* , 1989). De entre las numerosas características estructurales que podrían contribuir a explicar la diferencias entre sexos en la capacidad para generar impulso mecánico durante el esprín (tipo y longitud de la fibra muscular, ángulo de inclinación (penneación), longitud del fascículo y área de sección transversal de las fibras musculares) solamente el área de sección transversal de las fibras musculares difiere entre hombres y mujeres (Schantz *y col.* , 1983; Alway *y col.* , 1989; Miller *y col.*, 1993; Abe *y col.*, 1998; Abe *y col.*, 2001).

1.5.2 Área de sección transversal de las fibras musculares.

Se ha observado que existen diferencias en el área de sección transversal relativa (es decir, el área ocupada por la suma de todas las fibras del mismo tipo en relación al área de sección transversal total), entre hombres y mujeres, en el músculo vasto lateral en hombres las proporción es IIA > I > IIB (IIx, en la nomenclatura actual) mientras que en las mujeres la relación es I > IIA > IIB (IIx, en la nomenclatura actual) (Staron *y col.*, 2000). Dado que las fibras tipo II tienen una mayor capacidad glucolítica que las tipo I (Borges y Essen-Gustavsson, 1989; Stallknecht *y col.*, 1998) la masa muscular de los hombres presenta un mayor potencial para producir lactato que la masa muscular de las mujeres. Sin embargo, algunos estudios han mostrado respuestas de lactato similares entre sexos al realizar el mismo programa de ejercicios (Kraemer *y col.*, 1998; Pullinen *y col.*, 1999). Las diferencias en los resultados podrían ser debidas al protocolo de obtención de muestras de lactato, experiencia de los sujetos en los entrenamientos y diferencias en el programa diseñado (Crewther *y col.*, 2006).

La fuerza absoluta de las mujeres osciló entre el 40 y 60% de la fuerza de los hombres, pero estas diferencias entre sexos se eliminaron o fueron mínimas cuando la fuerza se expresó por kg de masa muscular (Doherty, 2001). Por lo tanto, la fuerza por unidad de masa muscular es considerada un mejor indicador de la función muscular que la fuerza a solas (Roubenoff y Hughes, 2000).

La velocidad de contracción de la fibra muscular es proporcional con la cantidad de actividad de la miosina ATPasa (Schluter y Fitts, 1994; Harridge *y col.*, 1996). Como las fibras tipo II tienen una mayor actividad de la ATPasa que las fibras lentas tipo I (Schluter y Fitts, 1994), parece claro que las fibras tipo II son necesarias para movimientos explosivos.

Teniendo en cuenta que la fuerza correlaciona positivamente con el área de sección transversal de la fibra muscular (Tesch y Karlsson, 1978) y con la velocidad de esprín (Alexander, 1989), y a pesar de que la fuerza entre sexos es similar cuando se expresa relativamente al área de sección transversal de la fibra muscular (Miller *y col.* , 1993), los hombres son capaces de desplegar una mayor fuerza absoluta que las mujeres debido a que la fuerza es proporcional a la masa muscular del esqueleto (Ford *y col.*, 2000).

1.5.3 Rigidez músculo tendinosa.

Aunque la potencia muscular es necesaria para acelerar y mantener la máxima velocidad en el rendimiento de un esprín, una alta rigidez músculo tendinosa en la pierna podría ser necesaria para una alta velocidad de carrera (Chelly y Denis, 2001). El papel que desempeña la rigidez de las extremidades inferiores en la velocidad máxima de carrera ha sido demostrada en animales, particularmente en lagartos (Farley, 1997). La rigidez de la pierna junto con la potencia hacia delante son los dos principales componentes implicados en el esprín (Cavagna *y col.*, 1971). Hay una relación significativa entre la rigidez de la pierna y la potencia calculada en el salto (Chelly y Denis, 2001). Además existe correlación entre la rigidez de la pierna calculada en un salto con la velocidad máxima de carrera en 40-m (Chelly y Denis, 2001).

Los hombres tienen una mayor rigidez músculo tendinosa que las mujeres tanto activa (Blackburn *y col.*, 2004; Padua *y col.*, 2005) como pasiva (Blackburn *y col.* , 2004). Estas diferencias indican que la musculatura masculina puede resistir más eficazmente cambios en su longitud que la femenina, lo que podría repercutir tanto a nivel de estabilidad articular como de producción de fuerza (Blackburn *y col.*, 2006). En teoría una mayor rigidez debería favorecer la capacidad para acumular energía potencial elástica en el curso del ciclo estiramiento acortamiento. No obstante, no se ha realizado aún ningún estudio en que se haya comparado el rendimiento en esprín entre hombres y mujeres usando modelos de ejercicio que permitan la utilización de los mecanismos de potenciación elástica, como por ejemplo el esprín en carrera y otros que no lo permitan como, por ejemplo, el esprín en ciclismo.

1.5.4 Volumen muscular.

Teniendo en cuenta que existe una relación positiva entre la rigidez y el volumen muscular (Chleboun *y col.*, 1997) podría ser que al tener los hombres más masa muscular esto implicará una mayor rigidez (Oatis, 1993; Chleboun *y col.* , 1997).

El volumen de masa muscular correlaciona con la máxima velocidad de carrera en 40-m, así como, con la potencia media desarrollada (Chelly y Denis, 2001). En líneas generales, los hombres tienden a ser más fuertes que las mujeres en todas las edades, sin embargo, la mayoría de estas diferencias son atribuibles a la mayor masa muscular de los varones (Doherty, 2001).

1.6 HIPÓTESIS.

1) El principal factor que explica las diferencias entre sexos en la capacidad de esprín es la masa muscular de las extremidades inferiores cuando en el esprín no interviene el ciclo estiramiento-acortamiento.

2) El rendimiento en esprín de carrera a pie se relaciona con la proporción de la masa corporal que representa la masa muscular de las extremidades inferiores.

3) Las diferencias entre sexos en la potencia media desarrollada en el Test de Wingate dependen de la masa muscular.

4) La mejora de la masa muscular con entrenamiento de fuerza se asocia a una mejora en el rendimiento en el Test de Wingate.

5) El entrenamiento de la musculatura extensora de las extremidades inferiores mediante la combinación de entrenamiento con pesas y pliometría se asocia a una mejora de la velocidad de la pierna en el chut.

6) El entrenamiento de la musculatura extensora de las extremidades inferiores mediante la combinación de entrenamiento con pesas y pliometría se asocia a una mejora de la capacidad de salto vertical

7) El entrenamiento de la musculatura extensora de las extremidades inferiores mediante la combinación de entrenamiento con pesas y pliometría se asocia a una mejora de la velocidad de carrera.

8) El entrenamiento de la musculatura extensora de las extremidades inferiores mediante la combinación de entrenamiento con pesas y pliometría se asocia a un aumento de la proporción de cadena pesada de miosina (MHC) tipo IIa en el músculo vasto lateral del cuádriceps.

1.7 OBJETIVOS.

1) Determinar si las diferencias en masa muscular entre sexos explican las diferencias entre sexos en el rendimiento de esprín en cicloergómetro.

2) Determinar si las diferencias en masa muscular entre sexos explican las diferencias entre sexos en el rendimiento de esprín en carrera.

3) Determinar si las niñas prepúberes que practican un entrenamiento específico de gimnasia rítmica 10 horas semanales, sin estar sometidas a un programa de entrenamiento específico de fuerza, tienen mayor masa muscular y capacidad de salto vertical que las niñas que no practican deporte extraescolar de forma habitual.

4) Determinar si 6 semanas de entrenamiento de fuerza combinando pesas y pliometría se asocian a una mejora de la velocidad de la extensión de la pierna al chutar.

5) Determinar si 6 semanas de entrenamiento de fuerza combinando pesas y pliometría se asocian a una mejora de la capacidad de esprín.

6) Determinar si 6 semanas de entrenamiento de fuerza combinando pesas y pliometría se asocian a una mejora de la capacidad de salto vertical.

7) Determinar si 6 semanas de entrenamiento de fuerza combinando pesas y pliometría se asocian a una mejora de la resistencia aeróbica.

8) Determinar si 6 semanas de entrenamiento de fuerza combinando pesas y pliometría producen hipertrofia muscular en las extremidades inferiores.

9) Describir los efectos de un programa de entrenamiento combinado de pesas y pliometría, de 6 semanas de duración sobre la proporción de isoformas de las cadenas pesadas de la miosina (MHC) en el vasto lateral de cuádriceps en hombres.

2. MÉTODO.

2.1 SUJETOS.

Las muestras de todos los estudios que forman parte de la tesis esta compuesta por dos grupos principales uno integrado por niñas y otro por adultos.

- Niñas. Se estudió a 26 niñas prepúberes residentes en Gran Canaria (edad 10.1 ± 0.8 años, masa corporal 34.1 ± 5.1 Kg, talla 140.1 ± 5.8 cm, datos expresados en valores medios ± SD, Tanner ≤ 2). Trece niñas que practicaban gimnasia rítmica diariamente con una frecuencia semanal de diez horas formaron parte del grupo experimental (GR), mientras que las otras 13 que no hacían actividad física de manera regular configuraron el grupo control (CO).
- Adultos. También fueron objeto de estudio 155 adultos, estudiantes de Educación Física, de los cuáles 123 eran varones (edad 23.6 ± 2.8 años, masa corporal 74.1±8.6 kg, talla 176.1 ± 6.3 cm, datos expresados en valores medios ± SD) y 32 mujeres (edad 23.3 ± 2.6 años, masa corporal 60.3 ± 5.7 kg, talla 165.1 ± 6.4 cm,).

2.2 MEDICIONES.

2.2.1 DESARROLLO PUBERAL.

El estado de desarrollo puberal se determinó mediante autoevaluación siguiendo el método Tanner (Tanner, 1962), que es un método de reconocida validez (Duke *y col.*, 1980) y reproductibilidad (r = 0.97) (Morris y Udry, 1980).

2.2.2 CONDICIÓN FÍSICA.

Rendimiento en el chut.

Un electrogoniómetro telemétrico (Gait Analysis System Mie Medical Ma 695110, Leeds, UK) se colocó en la cara lateral de la rodilla derecha para medir la velocidad angular de la articulación de la rodilla durante un chut máximo con el empeine. Además, un acelerómetro (Kistler 8632C50 Winterthur, Switzerland) fue colocado también en la cara media de la tibia, debajo de la tuberosidad tibial y se usó para identificar el tiempo en el cual la pierna impactaba con el balón de fútbol (Mikasa, Official size 5, Hiroshima, Japan) durante el chut. La velocidad angular de la rodilla alcanzada 10 ms antes del impacto fue utilizada como la máxima velocidad de extensión de la rodilla. Todos los datos fueron obtenidos con una frecuencia de muestreo de 1000 Hz y grabados en un PC utilizando un sistema de adquisición de datos (MacLab/8e, ADInstruments Pty Ltd. Castle Hill, NSW, Australia). Los sujetos realizaron tres chuts máximos con el empeine, sobre un balón parado, tan fuerte como fuera posible sin poner atención a la precisión del chut. La pierna de apoyo se situó 10 cm detrás y a la izquierda del balón. El chut en el que se alcanzó la mayor velocidad de extensión de la rodilla fue considerado el mejor de los tres intentos y fue seleccionado como el valor representativo del rendimiento en el chut.

Fuerza dinámica máxima (1 RM).

La fuerza dinámica máxima fue medida usando el 1 RM en prensa inclinada (ILP), extensiones de pierna (LE), media sentadilla (HQ), y flexiones de pierna (LC). En los ejercicios de ILP y HQ, los sujetos tuvieron que bajar la carga hasta alcanzar una flexión de rodilla de 90 grados. En LE, cada participante levantó el peso hasta conseguir la extensión de rodilla completa. En LC, cada sujeto levantó el dispositivo hasta que éste contactó con la parte posterior del muslo. En todos los ejercicios se animó verbalmente a los sujetos para que levantaran la carga desde la posición inicial. Antes de realizar el 1 RM los sujetos calentaron durante 10 minutos en un cicloergómetro Monark 818, posteriormente realizaron 10 repeticiones con una carga próxima al 50% aproximadamente de su 1 RM. Después hicieron dos levantamientos con cargas más pesadas hasta determinar el 1 RM. Para evitar problemas de fatiga los sujetos descansaron entre 3 y 5 minutos entre los intentos. Con este procedimiento en cinco intentos como máximo se alcanzó el 1 RM.

Fuerza dinámica e isométrica máxima.

Las fuerzas generadas durante el salto vertical se midieron mediante una plataforma de fuerza (Kistler, Winterthur, Suitzerland). Cada sujeto realizó dos tipos diferentes de saltos verticales máximos en los que se eliminó la contribución de los brazos: 1) Squat jump (SJ) en el que hay que saltar desde una posición de salida con las piernas flexionadas por la rodilla a 90º y en el que no se puede realizar contramovimiento previo, un goniómetro digital (Lafayette Instrument Company, Lafayette, IN) fue utilizado para verificar la flexión de rodilla a 90º antes de realizar el SJ. 2) Salto con contramovimiento (CMJ) en el que se parte de la posición de pie y se realiza un contramovimiento flexionando rápidamente las rodillas hasta unos 90º para conseguir impulso previo. A partir de los datos recogidos con la plataforma de fuerza se determinó la altura de vuelo (VJH), la fuerza máxima (Fp), siendo Fp = fuerza máxima – masa corporal), la potencia media (MP), el impulso mecánico positivo (PI) y la velocidad de desarrollo de fuerza (RFD) entre otras variables, en el mejor de tres intentos tanto en el SJ como en el CMJ. La RFD media fue calculada a través de regresión lineal mediante la relación de la fuerza-tiempo durante la fase de impulso en el SJ y CMJ entre el 25 y 75% del pico de fuerza.
La fuerza isométrica máxima (FIM) desarrollada durante la extensión de piernas en posición de sentadilla a 90º también se midió con la misma plataforma de fuerza, siguiendo el protocolo descrito por Calbet y colaboradores (Calbet *y col.*, 1998). Brevemente, a cada sujeto se le animó para que realizara lo más rápido posible la mayor fuerza que pudiera intentando mantenerla durante 5 segundos. Se guardaron los datos del mejor de tres intentos que se realizaron con al menos 1 minuto de recuperación entre ellos.

Capacidad anaeróbica.

Para estimar la capacidad anaeróbica se utilizó un test de carrera de 300-m. Este test fue elegido debido a que la capacidad anaeróbica es el principal determinante del rendimiento en esfuerzos máximos que llevan al agotamiento entre 30 y 60 s (Calbet *y col.*, 1997; Calbet *y col.*, 2003). El test se realizó en una pista de atletismo de 400-m y se midieron los tiempos mediante un cronómetro. A todos los sujetos se les pidió que corrieran los 300-m tan rápido como pudieran y los tests fueron efectuados individualmente, realizándose un sólo intento.

Test de velocidad de carrera.

El tiempo invertido en correr 30-m se midió utilizando células fotoeléctricas (General ASDE, Valencia). El cronómetro se ponía en marcha de forma automática cuando el sujeto cruzaba la primera célula, y de ahí en adelante tomaba los tiempos cada 5-m. Se motivó a los sujetos para que corrieran todo lo rápido que pudieran, y se tomó como valor representativo de la prueba el mejor de tres intentos separados por al menos por 1 minuto de descanso.

Potencia aeróbica máxima.

Para estimar el consumo máximo de oxígeno (VO_2max) se utilizó el test máximo de carrera de ida y vuelta de 20-m descrito por Leger y col. (1988). Se requería que los participantes corrieran entre dos líneas separadas 20-m, estando en cada línea en el momento en que sonaba un pitido emitido por una cinta magnetofónica. La frecuencia de las señales sonoras se incrementaba de tal forma que la velocidad de carrera que comenzaba a 8.5 $Km \cdot h^{-1}$ aumentaba en 0.5 $Km \cdot h^{-1}$ cada minuto. El tiempo que los sujetos eran capaces de correr se registró para calcular el VO_2max. Este test ha mostrado una gran validez y reproductibilidad para la predicción del VO_2max (Leger *y col.* , 1988).

Test de Wingate.

El Test de Wingate se realizó en un cicloergómetro Monark de freno mecánico (Monark 818E, Monark AB, Vargerg, Sweden) equipado con el sistema SRM power meter (Schoberer, Germany). Se utilizó una fuerza de frenado de un 10% de la masa corporal en los hombres y un 8% en las mujeres. Se utilizó doble correa para la fijación de los pies en los pedales. Los sujetos realizaron un calentamiento estándar que consistía en 10 minutos de pedaleo continuo a una intensidad cercana a los 80 vatios y al comienzo de los minutos 6º, 7º, 8º, 9º y 10º realizar un esprín de 6 segundos de duración. Después los participantes descansaban 5 minutos y realizaban el test de pedaleo a máxima intensidad durante 30 segundos con estimulación verbal por parte de los investigadores. Se determinó la potencia pico (PP), o máxima potencia desarrollada en un intervalo de 1 segundo, así como la potencia media (MP), o potencia promedio de las medidas registradas durante los 30 segundos que dura el test.

2.2.3 COMPOSICIÓN CORPORAL.

Masa muscular, masa ósea y porcentaje graso.

La masa magra (masa corporal – [masa grasa + masa ósea]) se determinó mediante absorciometría fotónica dual de rayos X (DXA) (QDR-1500, Hologic Corp., Software versión 7.10, Waltham, MA). El equipo DXA se calibró utilizando un fantoma de espina lumbar y siguiendo las recomendaciones de Hologic. Los sujetos se escanearon tumbados en posición supina y operando el escáner en la mayor resolución. A partir del análisis regional y de cuerpo entero se calculó la masa magra (g), la masa grasa (g), el área ósea total (cm2) y el BMC (g). El BMD se calculó siguiendo la fórmula $BMD = BMC \cdot área^{-1}$. También se realizó un análisis regional como se describe en Calbet y col. (2001). La masa magra de las piernas se asumió equivalente a la masa muscular.

También se realizaron dos análisis adicionales para estimar la masa ósea a nivel lumbar y de la parte superior del fémur izquierdo. Y además se presentan los valores de contenido y densidad mineral ósea del cuello femoral, el trocánter mayor, la zona intertrocanteriana y el triángulo de Ward, siguiendo las recomendaciones del fabricante.

Para la determinación de la masa ósea y masa magra de las extremidades inferiores (EEII) se utilizó absorciometría fotónica dual de rayos X (DXA). La mayor ventaja de ésta técnica de análisis de la composición corporal reside en su validez y fiabilidad (Mazess *y col.*, 1990; Haarbo *y col.*, 1991; Van Loan y Mayclin, 1992; Bailey *y col.*, 1996; López Calbet *y col.*, 1996). Además, se considera que es la técnica más adecuada debido, al tiempo tan corto de escaneado que necesita y a la baja irradiación, que es inferior, por ejemplo, a la radiación soportada en un viaje en avión de Las Palmas a Madrid (Lewis *y col.*, 2001).

Biopsias musculares.

Las biopsias musculares fueron obtenidas de la sección media del músculo vasto lateral bajo anestesia local. Antes y después del entrenamiento se obtuvieron biopsias en 25 de los sujetos. La muestra de tejido muscular fue inmediatamente montada y embebida en Tissue-Tek y congelada en isopentano enfriado con nitrógeno líquido, y guardada a – 80ºC. El análisis de la cadena pesada de miosina fue llevado a cabo en las biopsias musculares usando electroforesis en gel (SDS-PAGE, sodium dodecylsulfate polyacrylamide gel electrophoresis). En cada biopsia 20-40 secciones transversales (10 µm) fueron cortadas y sumergidas en 200-500 µL de tampón de lisis y calentadas durante 3 minutos a 90ºC. Entre 2 y 12 µl de esta suspensión fueron cargados en los geles de electroforesis y sometidos a 70 V durante 43 horas a 4ºC. Después, los geles fueron teñidos con Coomassie y la densidad óptica de las bandas de las isoformas de las cadenas pesadas de la miosina (MHC I, IIa IIx) fue determinada con el software Un-scan-it gel (Orem, UT).

2.3 CONSENTIMIENTOS Y APROBACIÓN ÉTICA.

Tanto los padres como los participantes fueron informados de forma verbal y escrita de los objetivos y procedimientos, así como de los posibles riesgos y beneficios de la participación en el estudio, tras lo cual firmaron la correspondiente autorización informada. El estudio se desarrollo de acuerdo a lo regulado para los estudios clínicos en la Declaración de Helsinki de 1975, y bajo la aprobación del comité ético u órganos competentes de la Universidad de Las Palmas de Gran Canaria.

2.4 ESTADÍSTICA.

Como estadísticos descriptivos se presentan los valores de la media y el error estándar de la media (SEM) o la desviación estándar (SD). Las diferencias entre los grupos se establecieron utilizando la prueba T para muestras independientes, tras comprobar la homogeneidad de las varianzas mediante el test de Levene. También se empleó un test de la covarianza (ANCOVA) con la masa corporal como covariable. Además, se examinó la existencia de relaciones lineales ente variables usando el test de correlación de Pearson y regresión lineal simple y múltiple. Para comprobar la similitud de las pendientes y puntos de intersección con la ordenada de estas relaciones, se aplicó la correspondiente prueba T para el modelo: $Yij = \alpha i + \beta iXij + \varepsilon ij$ for i = 1,2 (1 = varones, 2 = mujeres) y j = 1,…, n1 siendo εij i.i.d.

variables randomizadas siguiendo una distribución normal N(0, σ1). Las variables que mejor correlacionaron con el rendimiento fueron incluidas en el análisis de regresión lineal múltiple en pasos sucesivos para determinar que variables eran las más determinantes para predecir el rendimiento. Algunas de las comparaciones entre género fueron llevadas a cabo usando ANOVA con el género como factor con dos niveles. El análisis estadístico se realizó con el paquete informático SPSS (SPSS Inc., Chicago, IL, USA). Se han asumido diferencias significativas para $p < 0.05$.

3. RESULTADOS.

3.1 PAPEL DE LA MASA MUSCULAR EN EL RENDIMIENTO EN ESPRÍN.

En varones, la masa muscular absoluta de las extremidades inferiores correlacionó con el pico y potencia media en el Test de Wingate ($r = 0.66-0.73$, $p < 0.01$). En mujeres, la masa muscular de las extremidades inferiores correlacionó con el tiempo de carrera en 300-m, así como con el pico y la potencia media en el Test de Wingate ($r = -0.53, 0.66, 0.77$, respectivamente, $p < 0.01$) (Figura 1).

La masa muscular relativa de las extremidades inferiores correlacionó con el tiempo en 30-m y en 300-m, así como con el pico de potencia y la potencia media en varones ($r = -0.42, -0.38, 0.21, 0.23$, respectivamente ($p < 0.01$). También correlacionó con el tiempo en 300-m en mujeres ($r = -0.51$, $p < 0.01$) (Figura 2).

No se observaron diferencias significativas entre géneros en la pendiente de la regresión lineal entre la masa muscular de las extremidades inferiores y el pico o potencia media alcanzada en el Test de Wingate. Aunque la pendiente de la regresión lineal entre la masa muscular corporal y la potencia media fue significativamente más baja en las mujeres que en los hombres. Esto indica que la contribución de la masa muscular al pico de potencia y a la potencia media fue, esencialmente, similar en ambos sexos. Además, cuando el pico de potencia en el Test de Wingate fue dividido por los kilogramos de masa muscular de las extremidades inferiores el resultado fue casi idéntico en hombres y mujeres (50.4 ± 5.6 y 50.5 ± 6.2 W.kg de masa muscular^{-1}, en hombres y mujeres, respectivamente, $P = 0.88$). Sin embargo, cuando la potencia media en el Test de Wingate dividida por los kilogramos de masa muscular de las extremidades inferiores, los hombres consiguieron un valor un 22% más alto que las mujeres (26.6 ± 3.4 y 21.9 ± 3.2 W.kg de masa muscular^{-1}, en hombres y en mujeres, respectivamente, $P<0.001$).

El tiempo de carrera en 30-m dividido entre la masa muscular relativa de las extremidades inferiores fue significativamente más bajo en hombres que en mujeres (168.8 ± 16.9 y 233.7 ± 25.1 ms. % de masa muscular^{-1}, hombres y mujeres, respectivamente $P<0.001$). La pendiente de la regresión lineal entre la masa muscular relativa de las extremidades inferiores y el tiempo de carrera en 300-m no fue significativamente diferente entre sexos. Sin embargo, la pendiente fue mayor para las mujeres. Para un porcentaje dado de masa muscular relativa, los hombres consiguieron mejor rendimiento en el test de 300-m que las mujeres (1776.9 ± 198.8 y 2719.5 ± 358.7 ms. % de masa muscular^{-1}, hombres y mujeres, respectivamente $P<0.001$).

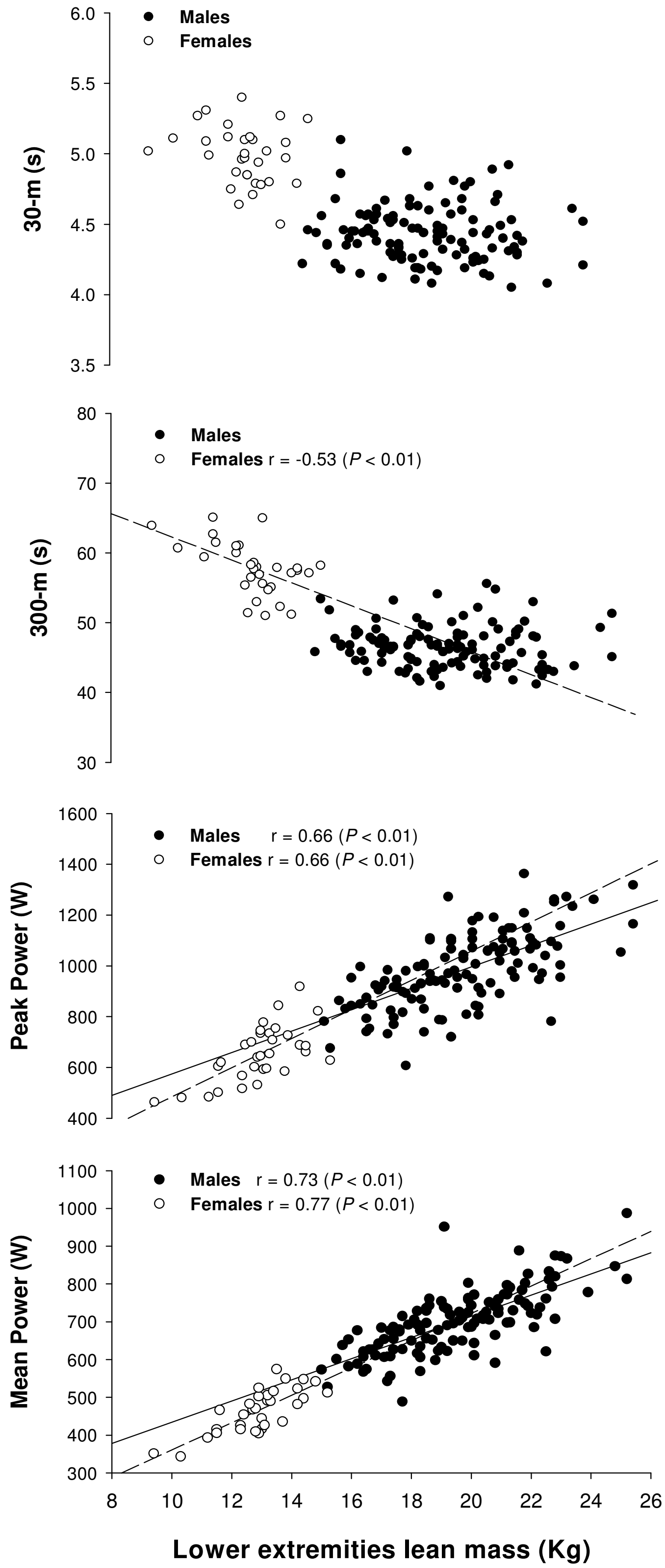

Fig. 1. Relación entre la masa muscular de las extremidades inferiores y 30-m, 300-m y rendimiento en el Test de Wingate.

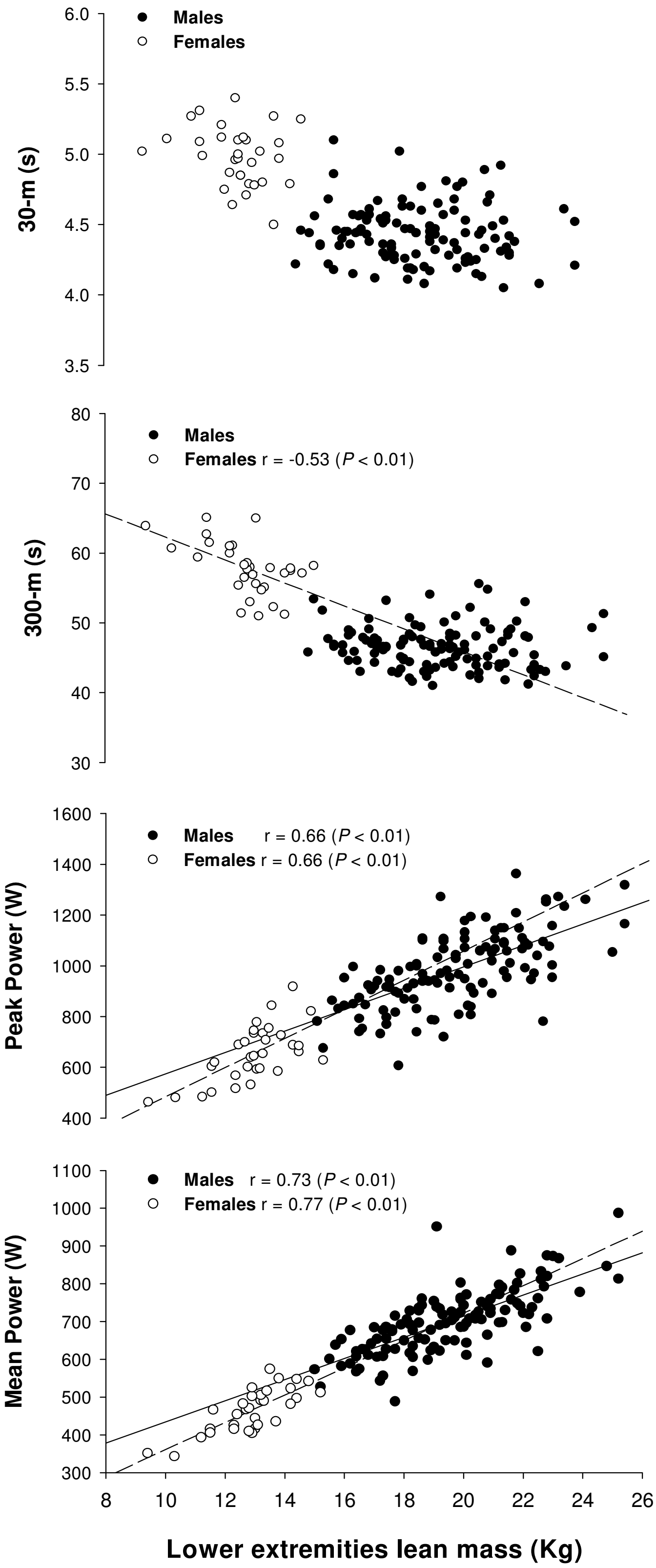

Fig. 2. Relación entre la masa muscular relativa de las extremidades inferiores (RLM = masa muscular * 100/masa corporal) y 30-m, 300-m y rendimiento en el Test de Wingate.

Correlaciones bivariadas.

La correlación entre el rendimiento en esprín de carrera y las variables medidas en el laboratorio se pueden observar en la tabla 1.

Tabla 1. Correlaciones bivariadas entre el rendimiento en el Test de Wingate, composición corporal y rendimiento en los esprines de carrera. Potencia pico (PP), potencia media (MP), masa corporal (BM), porcentaje de grasa corporal (%BF), masa muscular de las extremidades inferiores (LM), masa muscular total (TM), tiempo en recorrer 30-m (30-m) y 300-m (300-m). * P < 0.05.

Hombres	**300-m**	**30-m**	**%BF**	**LM**	**LT**
PP	-0.25 *	-0.36 *	-0.02	0.66 *	0.67 *
MP	-0.27 *	-0.34 *	-0.01	0.73 *	0.74 *

Mujeres	**300-m**	**30-m**	**%BF**	**LM**	**LT**
PP	-0.53 *	-0.66 *	0.03	0.66 *	0.57 *
MP	-0.44 *	-0.34	0.10	0.77 *	0.68 *

Hombres y mujeres	**300-m**	**30-m**	**%BF**	**LM**	**LT**
PP	-0.70 *	-0.72 *	-0.45 *	0.84 *	0.84 *
MP	-0.74 *	-0.72 *	-0.49 *	0.90 *	0.90 *

Cuando los hombres y mujeres se analizan conjuntamente en un solo grupo, la relación más intensa entre los resultados obtenidos en el Test de Wingate y la composición corporal fueron encontrados entre la potencia media y la masa muscular tanto total como relativa a las extremidades inferiores (r = 0.90, p < 0.01; tabla 1).

En los hombres, el tiempo en recorrer los 30-m correlacionó significativamente con PP (r = - 0.36) y MP (r = - 0.34), mientras que en mujeres la correlación fue significativa sólamente con la PP (r = - 0.66) (tabla 1). Sin embargo, ajustando la potencia en el Test de Wingate con la masa corporal total ($W.Kg^{-1}$) mejoraron estas correlaciones a r = -0.55 en hombres, y r = - 0.73 en mujeres (ambos p<0.05). Ajustando PP con la masa muscular de las extremidades inferiores se produjo un coeficiente de correlación ligeramente más bajo (r = -0.39 y r = -0.70, en hombres y mujeres, respectivamente, ambos p<0.05). De igual modo, al ajustar la potencia media por la masa corporal total dio una mejor correlación entre la MP y el tiempo de carrera en 30-m (r = -0.58 y r = -0.40, en hombres y mujeres, respectivamente, ambos p<0.05).

El tiempo en correr los 300-m correlacionó significativamente con la PP (r = - 0.25 y r = -0.53, en hombres y mujeres, respectivamente, ambos p<0.05). Ajustando el PP a la masa corporal total se obtuvieron mejores correlaciones (r = -0.41 y r = -0.64, en hombres y mujeres, respectivamente, ambos p<0.05). Sin embargo la correlación entre el 300-m y la PP fue ligeramente inferior cuando la PP fue ajustada con la masa muscular de las extremidades inferiores (r = -0.24 y r = -0.30, en hombres y mujeres, respectivamente, ambos p<0.05).

La correlación entre el tiempo de carrera en 300-m y la MP fue r = - 0.27 y r = -0.44, en hombres y mujeres, respectivamente (ambos p<0.05). Ajustando por la masa corporal la MP mostró mejores correlaciones (r = -0.46 y r = - 0.56, en hombres y mujeres, respectivamente, ambos p<0.05).

Análisis de regresión múltiple: 300-m como variable dependiente.

El análisis de regresión múltiple para predecir el rendimiento en el tiempo de carrera en 300-m en hombres, mujeres, y hombres y mujeres combinados en un solo grupo están descritos en la tabla 2. En hombres, este análisis muestra que el porcentaje de grasa corporal, la potencia media en el Test de Wingate y la edad son predictores significativos del tiempo de carrera en 300-m, explicando cada uno 19, 8 y 4% de la variablilidad en el tiempo de carrera. Cuando se incluye en el análisis de la regresión el rendimiento en el esprín de 30-m, éste tuvo el valor predictivo más alto para el tiempo en el 300-m en hombres, explicando un 23% de la variablidad en el tiempo en 300-m, mientras que el porcentaje de grasa corporal, MP y edad contribuyeron cada uno a explicar el 7, 4 y 3% de la variabilidad en el tiempo en 300-m, respectivamente.

Tabla 2: Predicción del tiempo de carrera en 300-m.

Hombres	**R**	**R^2**
%BF	0.45	0.19
MP	0.53	0.27
Age	0.58	0.32
300-m time = 308.94 (age) -10.60 (MP) + 233.95 (%BF) + 43088.46		
30	0.48	0.23
%BF	0.56	0.30
Age	0.60	0.34
MP	0.63	0.37
300-m time = -7.08 (MP) + 308.50 (age) + 160.21 (%BF) + 4583.71 (30) + 21475.87		

Mujeres	**R**	**R^2**
PP	0.58	0.32
%BF	0.68	0.42
300-m time = 195.55 (%BF) – 18.47 (PP) + 64595.71		
30	0.60	0.34
TM	0.72	0.48
300-m time = -0.42 (TM) + 9311.70 (30) + 28394.59		

Hombres y mujeres	**R**	**R^2**
MP	0.73	0.53
%BF	0.84	0.70
Age	0.85	0.71
300-m time = 244.74 (age) + 345.46 (%BF) -23.28 (MP) + 52152.06		
30	0.81	0.66
TM	0.86	0.74
%BF	0.88	0.77
Age	0.89	0.78
300-m time = 223.31 (age) + 186.21 (%BF) - 0.20 (TM) + 8379.86 (30) +12967.24		

En mujeres, el principal factor para explicar la variabilidad de la marca en 300-m fue la potencia pico alcanzada en el Test de Wingate, la cuál fue capaz de explicar un 32% de la variabilidad en el tiempo de carrera, mientras que el porcentaje de grasa corporal explicó el 10% de la variabilidad en el tiempo de carrera. Cuando el tiempo de carrera en 30-m fue incluido en el análisis de la regresión, éste fue capaz de explicar el 34% de la variabilidad en el tiempo de 300-m, mientras que la masa muscular corporal explicó el 14%. Cuando los hombres y las mujeres se combinaron en un solo grupo, la potencia media en el Test de Wingate fue el mejor predictor del tiempo de carrera en el 300-m, el cuál explico el 53% de la variabilidad en el tiempo en el 300-m. El porcentaje de grasa corporal y la edad explicaron un 17 y 1%, respectivamente de la variabilidad en el tiempo de carrera en el 300-m. Cuando el tiempo de carrera en el 30-m fue incluido en el análisis de la regresión, ésta variable fue capaz de explicar el 66% de la variabilidad en el tiempo del 300-m, mientras que la masa muscular total, el porcentaje de grasa y la edad explicaron un 8, 3 y 1% de la variabilidad en el tiempo de carrera del 300-m. El pico de potencia alcanzado durante el Test de Wingate, la masa muscular del cuerpo entero y la masa muscular de las extremidades inferiores explicaron un 11, 6, y 3% de la variabilidad en el tiempo de carrera del 30-m.

Análisis de regresión múltiple: 30-m como variable dependiente.

El análisis de la regresión múltiple para predecir el rendimiento en 30-m en hombres, mujeres y hombres y mujeres combinados en un solo grupo se muestra en la tabla 3. En hombres, el porcentaje de grasa corporal fue el mejor predictor del tiempo en 30-m, explicando un 13% de la variabilidad en el tiempo en 30-m. El pico de potencia alcanzado durante el Test de Wingate, la masa muscular del cuerpo entero y la masa muscular de las extremidades inferiores explicaron un 11, 6 y 3% de la variabilidad del tiempo de carrera en el 30-m. En mujeres el pico de potencia alcanzado en el Test de Wingate fue el mejor predictor del tiempo de carrera en 30-m, explicando un 42% de la variabilidad del tiempo de carrera en el 30-m, mientras que la masa muscular del cuerpo entero explicó un 9% de la variabilidad del tiempo de carrera en 30-m. Cuando hombres y mujeres se juntaron para formar un solo grupo, la potencia media en el Test de Wingate fue el mejor predictor del tiempo de carrera en 30-m, el cual explico el 52% de la variabilidad en el tiempo de carrera en 30-m. Variables adicionales con valor predictivo para el tiempo de carrera en 30-m fueron el porcentaje de grasa corporal, la masa muscular del cuerpo entero y el pico de potencia alcanzada en el Test de Wingate, las cuales explicaron un 9, 2, y 1% de la variabilidad del tiempo de carrera en el 30-m.

Tabla 3: Predicción del tiempo de carrera en 30-m.

Hombres	**R**	**R^2**
%BF	0.37	0.13
PP	0.50	0.24
LT	0.56	0.30
MP	0.60	0.33

30-m time = - 1.08 (MP) + 0.02 (LT) - 0.36 (PP) + 13.54 (%BF) + 4387.53

Mujeres	**R**	**R^2**
PP	0.66	0.42
LT	0.75	0.53

30-m time = 0.03 (LT) – 1.73 (PP) + 4977.34

Hombres y mujeres	**R**	**R^2**
MP	0.72	0.52
%BF	0.79	0.61
LT	0.80	0.63
PP	0.81	0.64

30-m time = -0.57 (PP) + 0.01 (LT) + 16.97 (%BF) – 1. 22 (MP) + 4921.11

El análisis de regresión múltiple en pasos sucesivos para predecir el rendimiento en el tiempo de carrera en 300-m y 30-m en hombres, mujeres, y en ambos incluidos en un solo grupo se presenta en las tablas 2 y 3 respectivamente. Dos ecuaciones diferentes fueron calculadas para cada distancia. Para la primera ecuación las variables incluidas en el análisis de regresión múltiple fueron: Pico de potencia (PP), potencia media (MP), masa muscular de las extremidades inferiores (LM) y masa muscular total (TM), porcentaje de grasa corporal (%BF) y edad. En la segunda ecuación las variables incluidas en el análisis de regresión múltiple fueron: Pico de potencia (PP), potencia media (MP), masa muscular de las extremidades inferiores (LM) y masa muscular total (TM), porcentaje de grasa corporal (%BF), edad, y el tiempo en correr los 30-m (ms) (cuando la variable predicha fue el tiempo en 300-m).

3.2. CAPACIDAD DE SALTO EN NIÑAS PREPÚBERES QUE PRACTICAN GIMNASIA RÍTMICA.

Las características generales así como los datos de composición corporal de los sujetos están resumidos en la tabla 4. Las niñas gimnastas presentan una masa corporal un 20% menor que las niñas control ($p < 0.05$) debido a un porcentaje de grasa corporal 8 puntos más bajo que el de las niñas control ($p < 0.05$) ya que la masa magra fue similar en ambos grupos.

Tabla 4. Composición corporal (media ± SEM) (GR = gimnasia rítmica; CO = niñas control).

Variables	GR	CO	Significación
Edad (años)	10.4 ± 0.9	9.9 ± 0.7	NS
Talla (cm)	138.8 ± 6.0	141.4 ± 5.4	NS
Masa corporal (Kg)	31.6 ± 3.4	36.5 ± 5.5	p<0.05
LT (Kg)	23.2 ± 2.9	23.9 ± 2.3	NS
MMB (Kg)	1.0 ± 0.1	1.0 ± 0.2	NS
MMP (Kg)	3.7 ± 0.7	3.8 ± 0.5	NS
% GC	21.0 ± 6.2	28.8 ± 7.3	p<0.01

Masa magra total (LT), masa magra media de las extremidades superiores (MMB), masa magra media de las extremidades inferiores (MMP), porcentaje de grasa corporal (%GC).

En la tabla 5 se muestran los resultados del test de salto vertical SJ y CMJ. Se realizó un análisis ANCOVA de las variables ajustando los valores respecto a la masa corporal. Los resultados demostraron que las niñas gimnastas obtuvieron una velocidad de despegue (VD, altura de vuelo (AV), impulso mecánico positivo (Ipos), y velocidad vertical máxima del centro de masas (Vimax) un 12, 25, 10 y 9% superior en el SJ respectivamente. Las diferencias fueron aún mayores (un 15, 34, 11 y 12%, respectivamente) en el CMJ con valores más elevados en las gimnastas que en las niñas control ($p < 0.05$). Además, durante el CMJ las niñas gimnastas desarrollaron una potencia instantánea máxima (Pimax) un 14% superior que las niñas control ($p < 0.05$). La potencia media por kg de masa corporal también fue superior en las gimnastas, tanto en los SJ como en los CMJs ($p<0.05$).

Tabla 5. Variables biomecánicas ajustadas para la masa corporal (media ± SEM) (GR = gimnasia rítmica; CO = niñas control).

	Variables	GR	CO	Significación
SJ	**Vd (m/s)**	1.91 ± 0.05	1.70 ± 0.05	< 0.05
	Av (cm)	18.8 ± 0.01	15.0 ± 0.01	< 0.05
	Tfmax (s)	0.23 ± 0.02	0.18 ± 0.02	NS
	Fmaxn (Kp)	34.0 ± 1.7	36.8 ± 1.7	NS
	Ipos (Kp.s)	6.5 ± 0.2	5.9 ± 0.2	<0.05
	Pm (w)	464.3 ± 19.4	492.6 ± 27.0	NS
	Vimax (m/s)	2.00 ± 0.05	1.83 ± 0.05	< 0.05
	Tvimax (s)	0.32 ± 0.15	0.28 ± 0.15	NS
	Pimax (w)	1082.2 ± 36.1	989.1 ± 36.1	NS
	Tpimax (s)	0.28 ± 0.16	0.24 ± 0.16	NS
CMJ	**Vd (m/s)**	2.09 ± 0.05	1.81 ± 0.05	< 0.01
	Av (cm)	22.4 ± 0.01	16.7 ± 0.01	< 0.001
	Tfmax (s)	0.33 ± 0.02	0.41 ± 0.02	<0.05
	Fmaxn (Kp)	49.4 ± 3.6	44.6 ± 3.6	NS
	Ipos (Kp.s)	7.03 ± 0.16	6.31 ± 0.16	<0.01
	Pm (w)	719.7 ± 32.1	679.0 ± 37.4	NS
	Vimax (m/s)	2.17 ± 0.04	1.94 ± 0.04	<0.01
	Tvimax (s)	0.53 ± 0.03	0.61 ± 0.03	NS
	Pimax (w)	1225.4 ± 42.3	1072.9 ± 42.3	<0.05
	Tpimax (s)	0.49 ± 0.03	0.56 ± 0.03	NS

Velocidad de despegue (VD), altura de vuelo (AV), tiempo necesario para alcanzar el valor máximo de fuerza (Tfmax), fuerza máxima neta (Fmaxn), impulso mecánico positivo (Ipos), velocidad vertical máxima del centro de masas (Vimax), potencia instantánea media (Pm) y máxima (Pimax), y el tiempo en alcanzar la velocidad vertical máxima del centro de masas (Tvimax) y el tiempo para alcanzar la potencia instantánea máxima (Tpimax)

En la tabla 6 se muestra la matriz de correlaciones entre las variables de composición corporal y las de salto vertical en ambos grupos conjuntamente. Siendo La Fmaxn, el Ipos, la Pm y la Pimax las que más intensamente correlacionaron con la masa magra total y regional en ambos saltos. También existe una correlación negativa entre la Av, Vd y la Vimax con el % GC en ambos saltos.

Tabla 6. Correlación entre algunas variables de salto vertical y variables de composición corporal, en las veintiséis niñas

Variables	MMB	MMP	LT	%GC
Av SJ	0.19	0.09	0.05	-0.45*
Vd SJ	0.22	0.11	0.08	-0.45*
Fmaxn SJ	0.52**	0.48*	0.49*	-0.11
Ipos SJ	0.43*	0.65**	0.70**	0.35
Pm SJ	0.36	0.52**	0.56**	0.21
Vimax SJ	0.23	0.16	0.12	-0.39
Pimax SJ	0.57**	0.72**	0.74**	0.15
Av CMJ	0.25	0.18	0.14	-0.46*
Vd CMJ	0.27	0.19	0.16	-0.47*
Fmaxn CMJ	0.56**	0.39*	0.41*	-0.33
Ipos CMJ	0.48*	0.73**	0.75**	0.31
Pm CMJ	0.61**	0.65**	0.66*	-0.78
Vimax CMJ	0.26	0.21	0.17	-0.42*
Pimax CMJ	0.64**	0.74**	0.74**	0.06

Salto con y sin contramovimiento (CMJ y SJ), altura de vuelo (AV), velocidad de despegue (Vd), fuerza máxima neta (Fmaxn), impulso mecánico positivo (Ipos), potencia instantánea media (Pm) y máxima (Pimax), velocidad vertical máxima del centro de masas (Vimax). Masa magra total (LT), masa magra media de las extremidades superiores (MMB), masa magra media de las extremidades inferiores (MMP), porcentaje de grasa corporal (%GC). $*P < 0.05$; $**P < 0.01$.

3.3 EFECTOS DEL ENTRENAMIENTO DE PLIOMETRÍA SOBRE EL RENDIMIENTO EN ESPRÍN EN CICLOERGÓMETRO.

Test de Wingate.

El grupo que realizó el entrenamiento pliométrico mejoró significativamente el pico de potencia y la velocidad de pedaleo máxima un 4% ($p < 0.05$) (Pérez *y col.*, 2004). Además se observó una tendencia hacia una mayor potencia media tras el programa de entrenamiento (+3%, $p = 0.09$) (Pérez *y col.* , 2004). Por el contrario, en el grupo control no hubo ningún cambio en las variables. El índice de fatiga tanto en valores absolutos como relativos a la masa corporal, o a la masa muscular de las extremidades inferiores, no se vio afectada por el entrenamiento.

3.4 EFECTOS DEL ENTRENAMIENTO COMBINADO DE PESAS Y PLIOMETRÍA SOBRE EL CHUT EN FÚTBOL, LAS ISOFORMAS DE LA CADENA PESADA DE MIOSINA Y EL RENDIMIENTO FÍSICO.

Composición Corporal.

Aunque el grupo de entrenamiento aumentó más la masa muscular de las extremidades inferiores que el grupo control no hubo diferencias significativas entre grupos en la masa muscular.

Rendimiento en el chut, salto vertical y fuerza dinámica máxima (1 RM).

El grupo de entrenamiento mejoró significativamente la velocidad angular máxima de la rodilla de 21.9 ± 1.3 a 24.5 ± 1.2 rad•s^{-1} ($p < 0.05$), mientras que el grupo control no mostró ningún cambio en esta variable. Sin embargo, no hubo correlación entre el incremento en la velocidad angular de la rodilla y los cambios en el rendimiento de las otras variables medidas en este estudio.

El grupo experimental también mejoró la velocidad de despegue de 2.41 ± 0.03 a 2.52 ± 0.04 m/s ($p < 0.05$), y la altura del salto de 0.30 ± 0.01 a 0.33 ± 0.01 m ($p < 0.05$), potencia máxima instantánea de 3341.6 ± 119.5 a 3545.3 ± 123.6 w ($p < 0.05$), conseguidos durante los SJ. También se mejoró en el CMJ la velocidad de despegue de 2.58 ± 0.04 a 2.74 ± 0.05 m/s ($p < 0.05$), altura del salto de 0.34 ± 0.01 a 0.39 ± 0.01 m $p < 0.05$), y la velocidad vertical máxima de 2.67 ± 0.04 a 2.80 ± 0.04 m/s ($p < 0.05$). Del mismo modo, el grupo experimental mejoró sus valores iniciales de impulso mecánico positivo de 19.1 ± 0.5 a 20.1 0.5 kgf/s ($p < 0.05$) y la potencia instantánea máxima de 3484.0 ± 114.6 a 3735.7 ± 114.4 w ($p < 0.05$). Sin embargo, el entrenamiento de fuerza estuvo asociado con una reducción en la velocidad media de desarrollo de fuerza de 843.3 ± 73.4 a 669.4 ± 72.3 kgf/s ($p < 0.05$).

El grupo experimental mejoró el rendimiento en el 1 RM en prensa inclinada de 203.5 ± 10.9 a 325 ± 13.8 kg ($p < 0.05$), extensiones de pierna de 67.2 ± 3.3 a 84.3 ± 3.5 kg ($p < 0.05$) y media sentadilla de 145.3 ± 6.5 a 208.2 ± 7.0 kg ($p < 0.05$).

Tests de Wingate y carrera.

No hubo efectos significativos del entrenamiento de fuerza sobre las variables analizadas del Test de Wingate o los tests de carrera.

Distribución de la cadena pesada de miosina.

El entrenamiento de fuerza se asoció a un incremento en el porcentaje de MHC tipo IIa de un 8.4% ($p < 0.05$) y una disminución en el porcentaje de MHC tipo I de un -5.2% ($p<0.05$). Antes del inicio del programa de entrenamiento, se observó una relación significativa entre el porcentaje de MHC tipo I y el VO_2max ($r = 0.52$, $p <0.01$). No se observaron correlaciones significativas en el grupo de entrenamiento entre los cambios en la composición de MHC tipo IIa y la mejora en el rendimiento del chut, saltos y fuerza dinámica máxima.

4. DISCUCIÓN GENERAL.

4.1 PAPEL DE LA MASA MUSCULAR EN EL RENDIMIENTO EN ESPRÍN

Las diferencias entre sexos en el rendimiento en esprín han recibido poca atención (Cheuvront *y col.* , 2005). Se sabe que los hombres tienen una potencia absoluta mayor que las mujeres y también una potencia relativa mayor cuando la potencia es expresada por kilogramo de masa corporal (Bar-Or, 1987; Vandewalle *y col.*, 1987a; Green, 1995). Nuestro estudio demuestra una asociación lineal entre la masa muscular absoluta de las extremidades inferiores y el pico de potencia durante el Test de Wingate. Además, esta relación es similar en hombres y mujeres hasta tal punto que en ambos grupos la potencia media alcanzada durante el Test de Wingate fue cercana a los 50 w por Kg de masa muscular de las extremidades inferiores. Además el análisis de regresión muestra que el pico de potencia aumenta linealmente en ambos grupos con la cantidad de masa muscular presente en las extremidades inferiores. El hecho de que la producción de potencia normalizada por la masa muscular de las extremidades inferiores es la misma en hombres y mujeres sugiere fuertemente que la principal razón de las diferencias entre sexos en el pico de potencia durante el Test de Wingate es que las mujeres tienen menos masa muscular en las extremidades inferiores.

Estudios sobre la fibra muscular esquelética han demostrado que son dos los principales factores que determinan la potencia de las fibras musculares: la máxima velocidad de acortamiento y la máxima tensión específica (fuerza isométrica máxima dividida entre el área de sección transversal (Malisoux *y col.*, 2006). La máxima velocidad de acortamiento depende de varios factores entre los que destaca el tipo de cadena pesada de miosina predominante, con una menor influencia de las cadenas ligeras de la miosina (Bottinelli, 2001). La fuerza isométrica máxima depende principalmente del área de sección transversal (Tesch y Karlsson, 1978). El área de sección transversal de la fibra depende de muchos factores: genéticos, hormonales, factores de crecimiento, nutricionales y mecánicos (Booth y Thomason, 1991; Russell *y col.*, 2000). No se han observado diferencias entre sexos en el tipo de fibra en seres humanos con estatus deportivo muy diferente (Costill *y col.* , 1976; Prince *y col.*, 1977; Schantz *y col.* , 1983; Sale *y col.* , 1987; Alway *y col.* , 1989). Además, entre los varios factores estructurales que podrían explicar las diferencias entre sexos en la capacidad de generación de fuerza tales como, el área de sección transversal, la tensión específica, la rigidez tendinosa, el ángulo de inclinación, la longitud de las fibras, la longitud de los fascículos, sólo se han observado diferencias marcadas en el área de sección transversal (Komi y Bosco, 1978; Schantz *y col.* , 1983; Alway *y col.* , 1989; Miller *y col.* , 1993; Abe *y col.* , 1998; Kumagai *y col.*, 2000) y en la rigidez de los tendones (Blackburn *y col.* , 2006), siendo ambos mayores en los hombres que en las mujeres. Se han observado diferencias entre sexos en la rigidez pasiva de los tendones de los flexores de rodilla (Gajdosik *y col.*, 1990; Blackburn *y col.* , 2004), el complejo articular de la rodilla (Oatis, 1993), el complejo articular del (Riemann *y col.*, 2001), estructuras tendinosas (tendón y aponeurosis) del gemelo interno (Chleboun *y col.* , 1997; Kubo *y col.*, 2003). También se han descrito diferencias entre sexos en la rigidez activa del tendón para los flexores de rodilla (Granata *y col.*, 2002b; Blackburn *y col.* , 2004) y las extremidades inferiores (Granata *y col.*, 2002a). Sin embargo, las diferencias entre sexos en la rigidez del tendón no son mayores que las diferencias en fuerza muscular, y en cada sexo la rigidez muscular es proporcional a la fuerza de los músculos activos (Bamman *y col.*, 2000). Aunque se han comunicado algunas diferencias entre sexos en la longitud de las fibras y en el ángulo de penneación (Kubo *y col.* , 2003) cabe esperar que los músculos con mayor capacidad para producir fuerza en función de la arquitectura tengan una mayor capacidad para resistir cambios en la longitud músculo tendinosa (es decir, muestren mayor rigidez) para un tamaño dado. Por lo tanto, sólo las diferencias entre sexos en la rigidez tendinosa no pueden explicar las diferencias entre sexos en el rendimiento en potencia, especialmente durante esprín en cicloergómetro.

En teoría la mayor flexibilidad de los tendones en mujeres debería permitir un mayor almacenamiento y liberación de energía durante actividades con participación del ciclo estiramiento-acortamiento tales como el correr o saltar (Komi y Bosco, 1978). Sin embargo, nuestros resultados no permitieron confirmar esta hipótesis. Este estudio demuestra que mientras las diferencias en la masa muscular absoluta podrían explicar la totalidad de las diferencias entre sexos en la producción de potencia pico durante un esprín en cicloergómetro, este no es el caso durante el esprín de carrera. El análisis de regresión múltiple empleada en este estudio indica que otros factores podrían jugar un importante papel, tales como la masa grasa corporal.

Los corredores de velocidad más rápidos ejercen mayor fuerza contra el suelo que los menos rápidos y no movimientos más rápidos de las piernas. Es probable que esto también se aplique a la comparación entre hombres y mujeres (Korhonen *y col.*, 2003). Los mejores esprínteres masculinos son un 7.3% más rápidos que las mejores mujeres esprínteres (Cheuvront *y col.* , 2005), posiblemente debido a que los hombres son capaces de generar más fuerza de reacción contra el suelo y, por lo tanto, zancadas más amplias (Korhonen *y col.* , 2003).

Nuestro trabajo también ha demostrado que la masa muscular puede explicar parte de las diferencias en la potencia media en el Test de Wingate y el tiempo de carrera en 300-m. No se observaron diferencias entre sexos en la curva que relaciona la masa muscular de las extremidades inferiores y la potencia media en el Test de Wingate, indicando que la potencia media aumenta con la masa muscular casi de la misma manera tanto en hombres como en mujeres. Sin embargo, el hecho de que la intercepción con la ordenada de esta relación fuese más baja en mujeres y que la potencia media en el Test de Wingate fuera un 22% más alta en los hombres sugiere que otros factores, además de la masa muscular deben contribuir a las diferencias en el rendimiento entre sexos durante esprines prolongados. Estos datos son ligeramente diferentes de los presentados por Weber y col. (2006), quienes estudiaron a 10 hombres y 10 mujeres y concluyeron que tras tener en cuenta las diferencias antropométricas la producción de potencia anaeróbica en hombres y mujeres es cualitativamente igual (Weber *y col.*, 2006). Las diferencias entre nuestro estudio y el de Weber y col. pueden ser debidas a que Weber y col. no utilizaron una estadística suficientemente adecuada para comparar las diferencias entre sexos tal y como hicimos en nuestro estudio.

La capacidad de sintetizar el ATP requerido para mantener la contracción muscular durante esprines prolongados es mayor en hombres que en mujeres, posiblemente debido a la mayor potencia aeróbica y anaeróbica de los hombres. Los hombres tienen mayor capacidad anaeróbica que las mujeres, especialmente debido a una mayor capacidad glucolítica (Komi y Karlsson, 1978; Green *y col.*, 1984; Simoneau y Bouchard, 1989; Jaworowski *y col.*, 2002). Las fibras tipo II tienen una mayor capacidad glucolítica que las tipo I (Essen-Gustavsson y Henriksson, 1984), y aunque no hay diferencias entre sexos en la distribución del tipo de fibras, el área ocupada por las fibras tipo II es mayor en los hombres que en las mujeres (Jaworowski *y col.* , 2002). Sin embargo, cuando la actividad de la lactato deshidrogenasa (LDH) y fosfofructoquinasa (PFK) son ajustadas por las diferencias entre sexos en el área de sección transversal las diferencias en la actividad de la LDH y PFK desaparecen (Jaworowski *y col.* , 2002). Esto esta de acuerdo con los resultados obtenidos en nuestro estudio mostrando que la masa muscular permite explicar gran parte de las diferencias entres sexos en la potencia media en el Test de Wingate. Sin embargo, nuestros resultados indican también que otros factores diferentes a la masa muscular absoluta y relativa podrían tener un papel importante. De hecho, se ha observado que los hombres también tienen una mayor capacidad anaeróbica que las mujeres incluso cuando el tamaño corporal es tenido en cuenta (Weyand *y col.*, 1993; Weber y Schneider, 2000; Mayhew *y col.*, 2001).

Durante un esprín que dura 30 segundos el 20-30% del ATP consumido es producido a través del metabolismo aeróbico (Medbo y Tabata, 1993; Calbet *y col.* , 1997; Parolin *y col.*, 1999; Calbet *y col.* , 2003). Un valor que alcanza alrededor del 50% de la energía total utilizada cuando la duración del esprín es cercana a 60 segundos (Medbo y Tabata, 1993). El VO_2max y el oxígeno consumido durante el Test de Wingate tienen una correlación alta, lo que significa que sujetos con un VO_2max alto son capaces de sintetizar una mayor cantidad de ATP durante el Test de Wingate a través del metabolismo oxidativo (Calbet *y col.* , 2003). Los hombres tienen mayor VO_2max (Lewis *y col.*, 1986) y capacidad oxidativa que las mujeres (Green *y col.* , 1984; Borges y Essen-Gustavsson, 1989).

Valor predictivo de la potencia desarrollada en el test de Wingate: potencia absoluta y relativa

Nuestros resultados indican que la producción de potencia tiene que ser normalizada en función de la masa corporal para que la producción de potencia durante el Test de Wingate tenga un valor predictivo alto para el rendimiento en esprín de corta (4-5s) o larga duración (50-70s). Estos resultados están en concordancia con otros estudios publicados (Baker *y col.* , 1994; Meckel *y col.*, 1995; Driss *y col.* , 1998). Los estudios con mayor heterogeneidad entre sujetos como, por ejemplo, el trabajo realizado por Meckel y col (1995) que estudiaron a un grupo de 30 sujetos con una variada capacidad de esprín (los tiempos medios de 100-m fueron de 11.1-s en el grupo más rápido y 14.2-s en el más lento) aportan los valores predictivos más altos para el rendimiento en esprín de producción de potencia normalizada por la masa corporal.

En general, la producción de potencia pico normalizada por la masa corporal tiene un mayor valor predictivo para el rendimiento en carrera en esprines cortos que el valor absoluto del pico de potencia. Utilizando la masa magra de las extremidades inferiores como la variable para normalizar no se consigue mejorar el valor predictivo del pico de potencia más allá de lo obtenido cuando la masa corporal es utilizada como variable de normalización.

De acuerdo con nuestros resultados, se ha comunicado que la producción de potencia media (W/Kg) en el Test de Wingate en mujeres muestra una correlación (r=-0.88) con el tiempo de carrera en 100-m (Meckel *y col.* , 1995). De igual modo, en hombres, se ha comunicado que la potencia media desarrollada durante un esprín de 10 segundos en cicloergómetro correlacionó con el tiempo de carrera en 40-m (-0.46) (Nesser *y col.*, 1996). Sin embargo, nuestro estudio muestra que el pico de potencia es más preciso para estimar el rendimiento en esprines cortos que para estimar la potencia media obtenida durante el Test de Wingate. Además, nuestros datos indican que el pico de potencia alcanzado en el Test de Wingate tiene también un valor predictivo para el rendimiento en el test de carrera de 300-m.

4.2 CAPACIDAD DE SALTO EN NIÑAS PREPÚBERES QUE PRACTICAN GIMNASIA RÍTMICA

Bencke y col. (2002) estudiaron a 185 niños y niñas que practicaban diferentes deportes, y observaron que los que realizaban gimnasia eran los mejores saltadores siendo su superioridad mayor al realizar DJ (saltos con caída o “drop jumps”), ejercicio que implica una coordinación motora más compleja. El SJ requiere solamente de una acción concéntrica y por lo tanto puede ser considerado como el salto más simple para analizar la fuerza explosiva. Por otro lado, el CMJ requiere una activación excéntrica previa a una alta contracción concéntrica, lo cual implica una mayor complejidad en su ejecución, y el DJ supone una importante carga excéntrica seguida de una alta contracción concéntrica, por lo que probablemente es más complejo desde el punto de vista neuromotor. Esta podría ser la razón por la cual la diferencia entre las niñas de rítmica y las niñas del grupo control son más acusadas en el CMJ que en el SJ (Bencke *y col.*, 2002).

Debido a que el sistema neuromuscular se desarrolla desde el nacimiento hasta la edad adulta, parece ser que la participación en prácticas deportivas puede inducir a alteraciones específicas en el control neuromuscular de los músculos de las extremidades inferiores, dependiendo de la naturaleza e intensidad del entrenamiento. En esta línea, diversos estudios sugieren que el entrenamiento de fuerza en niños puede inducir cambios en la activación neural e incrementar la fuerza (Blimkie, 1993; Ozmun *y col.*, 1994). Además, se sabe que la ejecución del salto vertical depende de la coordinación de las acciones segmentarias del cuerpo humano, las cuales dependen de impulsos del sistema nervioso central, que generan la activación secuencial y ordenada de los músculos que tienen que producir los momentos netos que alrededor de las articulaciones para ejecutar un salto vertical (Rodacki *y col.* , 2002). Por lo tanto, podría ser que la práctica de gimnasia rítmica mejore la coordinación en el salto vertical en niñas prepúberes.

Teniendo en cuenta que las ganancias de fuerza aumentan de una manera lineal con respecto a la edad, parece lógico pensar que en edades tempranas los niveles de fuerza alcanzados por los sujetos serán bajos y las diferencias observadas en los tests de salto puedan ser debidas a la propia coordinación o control neuromuscular. A este respecto, observamos que no existen diferencias significativas en cuanto a la fuerza máxima desarrollada durante el salto entre gimnastas y sedentarias.

Por otro lado, se ha observado que valores superiores de masa magra corporal total y menor porcentaje de grasa corporal se asocian a una mayor capacidad para generar impulso mecánico vertical lo que permite, en parte, una mayor capacidad de salto en jugadores profesionales de voleibol (23 años) (Ara Royo *y col.*, 2003). Sin embargo, en deportistas más jóvenes (15-16 años) no se observó correlación entre la altura del salto alcanzada con un CMJ y la cantidad de masa magra total, así como el % de grasa corporal (Ugarkovic *y col.* , 2002).

4.3 EFECTOS DEL ENTRENAMIENTO DE PLIOMETRÍA SOBRE EL RENDIMIENTO EN ESPRÍN EN CICLOERGÓMETRO.

Nuestros resultados muestran que el entrenamiento de pliometría durante 6 semanas es efectivo para mejorar el pico de potencia y la velocidad de pedaleo máxima, además de observarse una tendencia significativa hacia un valor superior de potencia media en el Test de Wingate en estudiantes de Educación Física.

Se ha demostrado que el entrenamiento de pliometría puede mejorar el rendimiento en movimientos explosivos como los saltos con contramovimiento (CMJ) (Diallo *y col.* , 2001; Matavulj *y col.* , 2001) o saltos sin contramovimiento (SJ) (Diallo *y col.* , 2001). En contraste con los resultados de otros estudios (Witzke y Snow, 2000; Siegler *y col.*, 2003), donde no se encontraron diferencias entre antes y después de entrenar en el pico de potencia y potencia media en el Test de Wingate (Siegler *y col.* , 2003), durante este estudio los jugadores continuaron con sus entrenamientos de fútbol, lo cual pudo influir en los resultados obtenidos (Siegler *y col.* , 2003). El estudio de Witzke y Snow (2000) presentaba una limitación ya que no se asignaron aleatoriamente los sujetos en los diferentes grupos, encontrándose que el grupo control fue físicamente más activo que el grupo de entrenamiento.

La mejora en el pico de potencia y velocidad máxima de pedaleo observada en nuestro estudio podría explicarse por un incremento en el porcentaje de las fibras musculares tipo II, o un cambio en la expresión de la isoforma de la cadena pesada de miosina desde las tipo I y tipo IIx a las tipo IIa, favoreciendo el desarrollo de contracciones musculares más fuertes y rápidas después del entrenamiento de pliometría. De hecho, se ha observado que 6 semanas de entrenamiento de esprín pueden mejorar el rendimiento en el esprín de carrera en sujetos con un nivel de entrenamiento similar al de nuestro estudio (Dawson *y col.*, 1998). Al igual que nosotros, Dawson y col. (1998) también observaron una mejora en el rendimiento en esprines prolongados, un resultado comparable con la mejora en potencia media observada en nuestro estudio.

4.4 EFECTOS DEL ENTRENAMIENTO COMBINADO DE PESAS Y PLIOMETRÍA SOBRE EL CHUT EN FÚTBOL, LAS ISOFORMAS DE LA CADENA PESADA DE MIOSINA Y EL RENDIMIENTO FÍSICO.

Seis semanas de entrenamiento de fuerza combinando pesas y ejercicio pliométrico en la misma sesión nos permitieron observar incrementos significativos en la velocidad de extensión de la pierna durante el chut, el porcentaje de cadena pesada de miosina (MHC) tipo IIa en el vasto lateral del cuádriceps, el salto vertical y la fuerza dinámica máxima (1 RM) en estudiantes de Educación Física.

Las velocidades angulares máximas durante el chut observadas en nuestro estudio oscilan entre 21.3-24.5 rad•s-1, siendo similares o un poco inferiores a las comunicadas por otros autores (Lees *y col.*, 2005; Manolopoulos *y col.*, 2006). En general, el rendimiento en el chut ha sido determinado a través de la medición de la distancia que alcanzaba el balón después de ser chutado (De Proft *y col.* , 1988), o mediante la velocidad de salida del balón tras ser golpeado (Trolle *y col.*, 1993; Aagaard *y col.*, 1996). En teoría, la velocidad del balón puede variar dependiendo de las características del balón y de la técnica de chut. Junto a estos factores, la distancia del chut posiblemente depende también del ángulo de salida del balón, la dirección del viento, la densidad del aire y de la técnica de chut. Por eso, para aislar mejor el efecto del entrenamiento de fuerza en la capacidad de chut nosotros medimos la velocidad angular de la rodilla, que es el principal factor determinante de la velocidad de salida del balón (Dorge *y col.*, 1999; Lees y Nolan, 2002). No medimos, sin embargo, el proceso de transferencia de energía desde el segmento proximal (muslo) hasta el distal (pierna) el cual también influye en la velocidad de salida al balón (Wickstrom, 1975; Dorge *y col.* , 1999). Se ha observado que la velocidad de la rodilla alcanza su máximo entre 40-70 ms después del pico de la velocidad de la cadera, mientras que las velocidades del tobillo y pie son máximas justo después del impacto, y 40-50 ms después del pico de velocidad en la rodilla (Isokawa y Lees, 1988).

El rendimiento en el chut se ha relacionado con la fuerza muscular de la pierna (De Proft *y col.* , 1988; Jelusic *y col.* , 1992; Dutta y Subramanium, 2002; Manolopoulos *y col.* , 2004), observándose correlaciones entre la fuerza de la pierna y el rendimiento en el chut. Igualmente, la mejora del rendimiento en salto vertical ha correlacionado con mejoras en la potencia de chut (De Proft *y col.* , 1988). Los resultados de nuestro estudio coinciden con otros estudios en lo que se observó una mejora en el rendimiento del salto vertical tras un entrenamiento combinado de pesas y pliometría (Bauer *y col.*, 1990; Adams *y col.*, 1992; Lyttle *y col.* , 1996; Fatouros *y col.*, 2000; Ingle *y col.*, 2006). La reducción en la velocidad media de desarrollo de la fuerza durante el salto vertical que hemos constatado en nuestro estudio concuerda igualmente con otro trabajo previo (Manolopoulos *y col.* , 2004). Sin embargo, a pesar de la disminución en la velocidad de desarrollo de la fuerza, la producción de potencia media no se redujo y el pico de potencia incrementó con el entrenamiento.

Las isoformas de la cadena pesada de miosina (MHC) determinan las propiedades contráctiles y energéticas de las fibras musculares humanas (Bottinelli y Reggiani, 2000). A pesar del incremento significativo en la isoforma de MHC tipo IIa en el grupo experimental no hubo correlación entre al incremento en la isoforma de MHC tipo IIa y el incremento en la velocidad angular de la rodilla, la fuerza dinámica máxima o el salto vertical. Nuestros resultados concuerdan con los de (Liu *y col.*, 2003). Sin embargo, también se ha comunicado ausencias de efectos importantes en la distribución de MHC a pesar del incrementos en fuerza muscular tras programas de entrenamiento de fuerza (Canepari *y col.*, 2005; Raue *y col.*, 2005).

En contradicción con nuestros resultados, otros estudios no encontraron mejoras en el rendimiento en el chut después de un programa de entrenamiento de fuerza en extensores de rodilla (Trolle *y col.* , 1993; Aagaard *y col.* , 1996). Las diferencias podrían ser debidas a que los participantes en nuestro estudio fueron estudiantes de Educación Física mientras que en estos dos estudios incluyen futbolistas de elite. Parece ser que los futbolistas tienen ya un rendimiento de chut alto con menos potencialidad para mejorar. El chut incorpora una serie de movimientos sinérgicos complejos difíciles de reproducir con el entrenamiento simple de fuerza (Bangsbo, 1994). Una de las grandes diferencias entre los estudios de Aagaard y Trolle con respecto al de Proft es que en este último los futbolistas además del entrenamiento de fuerza siguieron con su entrenamiento de fútbol, mientras que en aquellos sólo se realizó un entrenamiento de fuerza. Por lo tanto, parece ser que la combinación del entrenamiento de fuerza con el entrenamiento de la técnica de chut es necesario para mejorar el chut en futbolistas profesionales. Otra de las diferencias entre nuestro estudio y el de Aagaard y Trolle es que estos últimos analizaron varios grupos en los que trabajaban o cargas altas, o bajas o movimientos de chut con resistencia en el proceso del entrenamiento, mientras que nuestros sujetos entrenaron con cargas altas y medias y bajas, además de con movimientos explosivos en la misma sesión. Por lo tanto, el estímulo para nuestros sujetos puede haber sido mayor y más específico que para los futbolistas de los estudios de Aagaard y Trolle. Otra posible diferencia entre los estudios fue que nuestros individuos realizaron un chut máximo tan rápido como fuera posible sin prestar atención a la precisión, mientras que sus futbolistas chutaron hacia una portería de balonmano y sólo los tiros dentro de la portería fueron aceptados como válidos, esto podría haber condicionado la habilidad para alcanzar la máxima potencialidad de mejora en el chut. Sin embargo, este hecho debería haber afectado al chut por igual tanto antes como después de entrenar.

5. RESUMEN Y CONCLUSIONES.

Esta tesis aporta nuevos conocimientos sobre los efectos del entrenamiento pliométrico y de levantamiento de pesos sobre la mejora en el rendimiento en varios tests de condición física y en la potencia de chut en el fútbol, también resalta la importancia que tienen tanto la masa muscular como la grasa corporal de cara al rendimiento en esprín. Las principales conclusiones alcanzadas con los estudios integrados en esta tesis doctoral son:

1) El principal factor que explica las diferencias entre sexos en la capacidad de esprín es la masa muscular de las extremidades inferiores cuando en el esprín no interviene el ciclo estiramiento-acortamiento. Tanto en hombres como en mujeres la potencia pico durante un esprín en cicloergómetro alcanza un valor medio de 50 vatios por kilogramo de músculo esquelético en las extremidades inferiores.

2) El rendimiento en esprín de carrera a pie se relaciona con la proporción de la masa corporal que representa la masa muscular de las extremidades inferiores.

3) El rendimiento en esprín prolongado puede explicarse parcialmente debido a las diferencias entre sexos en masa muscular y en masa grasa.

4) El valor predictivo de la producción de potencia durante un Test de Wingate o un esprín en carrera es mayor si la potencia es expresada relativamente a la masa corporal más que en valor absoluto.

5) La práctica continuada de gimnasia rítmica en edades prepúberes se asocia a un mayor rendimiento en el salto vertical tanto en el SJ como en el CMJ. Nuestros resultados sugieren que la mayor capacidad de salto de las niñas que practican gimnasia rítmica, comparadas con las niñas que no practican deporte de forma regular no es debida a diferencias en la masa muscular. Otros factores relacionados con la composición fibrilar de la musculatura y con la coordinación del salto podrían explicar las diferencias observadas.

6) Seis semanas de entrenamiento de pliometría permiten mejorar el pico de potencia y la velocidad de pedaleo máxima en el Test de Wingate.

7) Seis semanas de entrenamiento combinado de pesas y pliometría mejoran significativamente la velocidad de extensión de la pierna en chuts efectuados a máxima velocidad.

8) Seis semanas de entrenamiento combinado de pesas y pliometría mejoran la capacidad de salto vertical.

9) Seis semanas de entrenamiento combinado de pesas y pliometría no mejoran la velocidad de carrera en 30 metros.

10) Seis semanas de entrenamiento combinado de pesas y pliometría producen un aumento de la proporción de cadena pesada de miosina (MHC) tipo IIa en el músculo vasto lateral del cuádriceps.

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9. APÉNDICES – Publicaciones I-VI.

I. Jorge Perez-Gomez, José A. L. Calbet. **Training to improve vertical jump performance.** Sports Medicine. (enviado).

II. Jens Bangsbo, Magni Mohr, Allan Poulsen, Jorge Perez-Gomez and Peter Krustrup **Training and testing the elite athlete.** J Exerc Sci Fit. Vol 4, nº1, 1-14, 2006.

III. Jorge Perez-Gomez, Germán Vicente Rodriguez, Ignacio Ara, Hugo Olmedillas, Safira Delgado-Guerra, Javier Chavarren, Juan José Gonzalez-Enriquez, Cecilia Dorado, José A. L. Calbet. **Role of muscle mass on sprint performance.**

IV. Jorge Perez-Gomez, Germán Vicente-Rodriguez, Ignacio Ara, Rafael Arteaga, José A. L. Calbet. **Capacidad de salto en niñas prepúberes que practican gimnasia rítmica.** European Journal of Human Performance 15, 2006.

V. Jorge Perez-Gomez, Germán Vicente-Rodriguez, Ignacio Ara, Javier Chavarren, José A. L. Calbet. **Influence of jumping plyometric training on cycling sprint performance.** European Journal of Human Performance. 11 (41-49), 2004.

VI. Jorge Perez-Gomez, Hugo Olmedillas, Safira Delgado-Guerra, Ignacio Ara Royo, Germán Vicente-Rodriguez, Javier Chavarren, José A. L. Calbet.. **Effects of weight lifting combined with plyometric exercises on kicking in football, myosin heavy chain isoforms, and physical performance.** Journal of Sport Science. (enviado).

Training to improve vertical jump performance

Jorge Perez-Gomez and Jose A. L. Calbet

Department of Physical Education, University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Canary Island, Spain.

Running head: Training and vertical jump performance.

Address Correspondence to: J.A.L. Calbet
Departamento de Educación Física
Campus Universitario de Tafira
35017 Las Palmas de Gran Canaria
Canary Islands
Spain
Fax: 34-928-458867
e-mail: lopezcalbet@terra.es

Contents

Abstract

This review provides an overview of the methods used to improve vertical jump and the mechanisms by which they act. Although many training routines have been proposed, these can be grouped in four main categories: plyometric training, resistance training (weight lifting), whole body vibration treatment and electromyostimulation training. Plyometric and weight lifting training are the methods of training more commonly used and best studied. Plyometric training enhances muscular force, the rate of force development, muscular power and muscle contraction velocity. These effects have been shown in children, physically active subjects and elite athletes. Plyometric training enhances the mean cross-sectional areas of type I, IIa, and IIa/IIx, the unloaded shortening velocity and peak power in all muscle fibers with type II fibers showing the greatest improvement, without a significant enhancement of the specific isometric tension (force/cross-sectional area). Plyometric training may also enhance muscle stiffness allowing greater storage and release of elastic energy. Although irrefutable experimental evidence is lacking, it has been suggested that plyometric training may also elicit increased inhibition of antagonist muscles after training, better co-contraction or increased activation of synergistic muscles, reduction of neural inhibitory mechanisms and increased agonist motoneuron excitability and synchronisation. Ballistic weight training has also been associated to improvements in force, velocity, power output, and rate of force development during jumping on a force plate. It seems that the best results may be achieved through the combination of weight lifting and plyometric exercises. Some authors have found an increase in vertical jump performance with the use of whole body vibration while other did not see such an effect. Moreover, the mechanism by which whole body vibration could improve jumping performance remains elusive. Electromyostimulation has also been reported as an

efficient method to improve vertical jump performance, however this methods has always been applied concomitantly with either weight lifting or plyometric training. The lack of appropriate control groups and lack of muscle biopsies to analyse the structural changes induced by the electrical stimulation programs preclude any definitive conclusion about the efficiency of electromyostimulation to improve vertical jump. EMS beyond that attainable with, for example, plyometric training combined with weight lifting. In summary, a bulk of scientific evidence suggests that the best way to improve vertical jump performance is through the combination of weight lifting and plyometric training. Further research is needed to establish if better results are possible by more complex strategies combining several of theses methods.

Vertical jump capacity is associated with success in many sports by increasing the efficacy of numerous athletic skills, such as heading in soccer, rebounding in basketball, spiking in volleyball (1-4), beside a significant relationship has been observed between the team average for jump height and team success in soccer (5). Vertical jump capacity depends in part on the lower extremities muscle power and, hence has been used as a standard tests of power performance (6-8) and it has been used to estimate the composition of the muscular fibers (9). In addition, the assessment of vertical jump performance is also interesting professionals since jumping height is directly related to bone mass (10) and negatively related to fat mass (11, 12). Physical activity that involves high impacts such as jumping, has a positive effect on the gain of bone mass and density, specially in loaded bones (13-15).

To improve vertical jump performance a greater vertical velocity at takeoff is required (16) which may be achieved by a higher contraction velocity and/or muscle force of the extensor muscles of the trunk, hip and lower extremities. Several studies have examined the effects of a wide variety of resistance training methods on vertical jump improvement, which include: plyometric training (17-22), resistance training (23-28), eletromyostimulation training (29-32) and whole body vibration (WBV) treatment (33-36). All these methods have been studied alone or in combination of one or more methods (37-40). Therefore, in the present review we are going to focus on describing the training methods applied to improve vertical jump performance and the mechanisms by which they may act.

Why is resistance training used?

The rationale for the use of resistance training to improve vertical jump performance relies on the close relationship observed between the maximum dynamic force of the lower extremities and the maximum height achieved during vertical jumping (41). In addition, subjects with higher isometric force and/or enhanced rate of force development during knee extension have also better vertical jump performance (42). Similarly, Hubley and Wells (43) have demonstrated that the activation of the femoral quadriceps contributes 50% of the work applied in the vertical jump. Vanezis and Lees (44) investigated further into the contribution made by the lower limb joints to vertical jump performance by good and poor performers of the counter-movement jump. The study showed that better jumpers demonstrated greater joint moments, power and work done at the ankle, knee and hip, and as a result jumped higher under both conditions. The authors concluded that the superior performance of the better jumpers was due to greater muscle capability in terms of strength and rate of force development in all lower limb joints rather than to technique, which differed less noticeably between the groups. According to Vanezis and Lees (44) the muscle strength characteristics of the lower limb joints are the main determinants of vertical jump performance with execution technique having less of an effect. In contrast, no effect of endurance training on vertical jump performance has been reported in soccer players (45).

Plyometric training

Stretch shortening cycle (SSC)

During the plyometric exercise, the muscles can develop its maximum strength in the shortest time; it involves a quick sequence of movements called stretch shortening cycle (SSC). During the SSC two difference phases can be observed: a first eccentric contraction followed immediately by a fast concentric contraction (shortening). In the eccentric contraction the muscles contract to perform a rapid deceleration to brake rapidly the downwards movement of body mass centre. This involves the lengthening of the contracting agonist musculature (stretching). During the fast concentric contraction (shortening) the centre of body mass is accelerated in the upward direction. The training based on the use of the SSC is purported with the main aim of improving muscular power. The three main mechanisms have been proposed to explain how a SSC allows for a higher production of force at a faster speed: mechanical potentiation, higher force application time and post-activation potentiation.

Mechanical potentiation. It is believed that SSC evoke the elastic properties of the muscle fibers after a quick stretching of the tendon-muscle structure, which allows muscles to store energy in the series elastic elements during the eccentric phase. This energy is released quickly and if the stretching is immediately followed by a concentric muscular action, part of this energy contributes to enhance the power generated during the concentric phase (46-49). However, if the time delay between the stretch and the concentric contraction is too long, the energy stored in the elastic elements dissipates as heat. Another advantage is that previous stretching decreases the time in which positive work is done during the subsequent shortening (50). However, the contribution of the elastic recoil as a potentiation mechanism during the SSC has been questioned (51-53) and may be limited only to certain tendon-muscle structures such as the triceps-suralis-Achilles tendon complex (54-56), while the biomechanical design of the quadriceps muscle and the patellar tendon allows for a lower contribution of this mechanism (51). This is in agreement with the view that, for any muscle-tendon unit, a "trade-off" exists with respect to "position control" vs. "energy storage" that is directly related to the design of the tendon (thick and short vs. long and thin) and that proximal leg extensors mainly exhibit the ability to control position (or force transmission) while the Achilles tendon is better suited for storage-recoil of elastic energy (57).

Higher force application time. During a vertical jump the time available to generate tension is rather short (in general less than 0.4 s) (58, 59), i.e. substantially less than required to attain the maximal isometric force. The peak force achieved during the SSC may be enhanced by increasing the time available for muscle contraction. In agreement with this view, Svantesson et al. (56) showed that the level of force developed during a concentric muscle contraction is enhanced by a preceding eccentric contraction, which allows for storage of elastic energy but also by a preceding isometric contraction which does not allow for a significant accumulation of elastic energy. However, the degree of potentiation was larger with eccentric than with isometric preceding action, regardless of movement velocity (56). The latter study showed that the main reason for larger concentric torque values after a preceding muscle action is that time is sufficient for maximal muscle tension development (56). Although, elastic energy is stored, particularly during a preceding eccentric action and under certain circumstances may also contribute to enhance vertical power.

Post-activation potentiation (posttetanic potentiation). Muscle post-activation potentiation is defined as the enhancement of the rate of force development caused by contractile activity prior to a given muscle contraction. This phenomenon was noted first by Ranke (60), who described that with stimuli uniform in strength the later twitch contractions were stronger than the first. Since then, there has been considerable interest in identifying the mechanisms involved in isometric twitch potentiation during trains of stimuli at low frequency (staircase) or after a tetanus (posttetanic potentiation). Several forms of contractile activity have been shown to elicit posttetanic potentiation by studying the effect of prior contractile activity on muscle twitches. A twitch is an isolated muscle contraction of short duration caused by a single presynaptic action potential or a single synchronised volley of action potentials (61). The peak force, the rate of force development and the time needed for force to attain maximal values are enhanced following a sustained maximal voluntary contraction (MVC) (62-66); an evoked tetanic contraction (67, 68) and repeated sub-fusion stimuli (69) that depends on the frequency used during the repeated sub-fusion stimuli (70).

Several mechanisms have been considered for post-activation potentiation such as changes in compliance of the series elastic elements, activation of more fibers within a muscle, increased Ca^{2+} release within a single fiber to activate fully the contractile proteins, and changes in excitation-contraction coupling processes (71-74). However, the chief underlying mechanism of post-tetanic potentiation is the phosphorylation of myosin regulatory light chains (71, 75, 76). This phosphorylation by the Ca^{2+}/calmodulin-dependent skeletal muscle myosin light chain kinase (skMLCK) (77) (Fig. 1). Phosphorylation of skeletal muscle myosin regulatory light chains potentiates the force and speed of contractions that are dependent on Ca^{2+} binding to troponin on actin-containing thin filaments (Fig. 2), but it has no significant effect on skeletal muscle actin-activated myosin ATPase activity (78, 79). This phosphorylation induces a conformational or structural alteration of the S1 fragment of the myosin molecule leading to an increase in the rate at which myosin cross-bridges move from a non-force producing state to a force producing state (78-80). Additional mechanisms for posttetanic potentiation should also be considered. For example, calmodulin modulation of the L-type Ca^{2+} channel and ryanodine receptor (81-83), raising the possibility that stimuli with repetitive Ca^{2+} release could affect the functions of these two proteins and thereby alter excitation-contraction coupling properties. Thus, during repetitive motor unit firing at physiological frequencies that initiate unfused tetanus, muscle force may be enhanced by multiple mechanisms involving Ca^{2+}. Moreover, apart from the known skMLCK, regulatory light chains may be also phosphorylated by other kinases present in the skeletal muscle fibers, such as the smooth muscle MLCK (smMLCK) (77, 84). In agreement, the disruption of the MYLK2 gene to eliminate the expression of skMLCK suppresses most of the regulatory light chain phosphorylation in response to contractile activity, but does not eliminates it completely (77). Knocked-out mice of MYLK2 gene have a reduced capacity for posttetanic potentiation (77). Thus most scientific evidence indicates that the main mechanisms by which posttetanic potentiation occurs is mediated initially by Ca^{2+} released during membrane excitation, which, then, stimulates contraction by binding to troponin on thin filaments but also activates skMLCK by means of Ca^{2+} binding to calmodulin to evoke phosphorylation of the regulatory light chain of skeletal muscles. A small portion of MLCK is activated by the intracellular Ca^{2+} transient associated with a single twitch (77). However, with repetitive contractions, more activated kinase accumulates due to the slow rate (1 s^{-1}) of inactivation induced by Ca^{2+}/calmodulin dissociation (79). In turn, the phosphorylation of myosin regulatory light chains increases the number of cross bridges in the strong-binding state by their displacement away from the myosin thick filament toward the actin thin filament. Yang et al. (85) hypothesized that the mechanism by which phosphorylation of myosin regulatory light chains potentiates force in mammalian striated muscle if by moving the myosin head closer to the thin filament (Fig 3). In agreement with the hypothesis of Yang et al. (85) it has been shown that compression of skeletal muscle fibers, either by increasing sarcomere length or by osmotic compression, which also reduce the distance between thin and thick filaments mimics the effect of myosin regulatory light chain phosphorylation on twitch potentiation (78, 79, 85, 86). In addition, the fact that dephosphorylation myosin regulatory light chains is slow (minutes) (87, 88) fits well with the prolonged duration of posttetanic potentiation further supports that this is the main mechanisms to explain postetanic potentiation.

For posttetanic potentiation to play a role in enhancing the rate of force development during a single stretch-shortening cycle a significant level of phosphorylation of the myosin regulatory light chains should be achieved in the short duration of the eccentric phase (about 0.3 seconds). In contrast, the rate of myosin regulatory light chain phosphorylation by the Ca^{2+} calmodulin skMLCK (89), is rather slow with little phosphorylation occurring during the initial second of stimulation (79). In fact, after the single l-s tetanus, Ca^{2+} concentrations rapidly return to control values, while light chain phosphorylation continues for 4-10 s (87, 88, 90). Thus, phosphorylation of myosin regulatory light chains can not explain the gain in power generation achieved during a single fast concatenation of an eccentric and a subsequent concentric muscle contraction. However, repeated muscle contractions can lead to a higher level of basal phosphorylation of the myosin regulatory light chains which may last several minutes and contribute to enhance the rate of force development during subsequent muscle contractions without any effect on maximal isometric force (79). In fact, some studies have reported improvements in peak power output, rate of force development during a maximal isometric contraction or performance in ballistic muscle actions that were carried out between few seconds and 20 minutes after maximal voluntary contractions or repeated heavy loaded muscle contractions (91-98). Since no assessment of the degree of phosphorylation of myosin regulatory light chains or twitch potentiation was performed in these studies (91-98), the effect reported can not be ascribed to post-activation potentiation. Other studies have failed to show any positive influence of post-activation potentiation on muscle performance (64, 99). Gossen and Sale (64) studied six men and four women who performed, in separate trials, maximal dynamic knee extensions with loads of 15%, 30%, 45% and 60% of maximal isometric knee extension peak torque (MVC). The dynamic extensions were done after post-activation potentiation had been induced with a 10-s MVC, and in a control trial without post-activation potentiation. This protocol evoked post-activation potentiation as determined by the increase in evoked twitch torque. Despite the achievement of post-activation potentiation the authors report that this protocol failed to increase the attained peak velocity with any load; on the contrary, they observed a trend for peak velocity to decrease in the first extension, which occurred approximately 15 s after the 10-s MVC. Gossen and Sale (64) suggest that fatigue produced by the 10-s MVC suppressed any potential benefit that could be derived from the induced post-activation potentiation.

Effects on jumping performance

In theory the improvements elicited by plyometric training in terms of muscular force, muscular power and speed of muscular contraction (1, 100, 101) could be caused by the structural and functional changes affecting the mechanisms of muscular activation and coordination. However, it is still not known if some of these mechanisms have a major roll or whether the conjugation of several of mechanisms permits an increase the muscular power through plyometric training. Nevertheless, plyometric training has become very popular method to improve vertical jump. Although, some studies were contradictory (102), or have shown significant improvement in CMJ but not in SJ (103), plyometric training has been proposed as an effective method to improve explosive force and vertical jump performance (Table I) in physically active subjects (1, 20, 100, 104-108), children (18), and elite athletes (21). Aquatic plyometric training (APT) seems to elicit similar benefits, but with reduced risks due to the buoyancy of water (109).

Matavulj et al. (21) showed that 6 weeks of plyometric training 3 times a week improved vertical jump performance in elite junior basketball players. Similarly, Hakkinen et al. (110) reported that plyometric training allowed for an increase in the maximal rate of force development and consequently the muscular power, even in prepubescent boys (18). However, Wilson et al. (103) showed that plyometric training resulted in significant improvements in CMJ but not necessarily in the SJ jumped height, they suggested that plyometric training enhances the ability of subjects to utilise the elastic and neural benefits of the SSC.

The Drop Jump (DJ) is one of the most popular plyometric exercises, in which subjects jump down from an elevated platform and when they make contact with the floor, execute a maximal vertical jump. In many cases, DJ training utilises the body weight as the overload with an emphasis on a short contact time and maximum effort during the subsequent vertical jump. Several studies have shown that the training with DJ produces significant improvements in the vertical jump performance in adults (38, 103) and children (18, 111). Plyometric training using DJs from different heights improves the rate of force development (110). According to Bobbert (1) it is very important to control the technique of execution of the DJ, as the technique of the jump has a significant effect on the dynamics of force generation. This author distinguishes two types of DJs: the countermovement drop jump (CDJ) and the bounce drop jump (BDJ) (1). In the CDJ the eccentric phase is larger and generally reaches a knee flexion of 90 degrees. In the BDJ the knee flexion is smaller, with an angle higher than 90 degrees. The BDJ is executed quicker than CDJ and with a smaller amplitude of movement. Consequently, the power developed in a BDJ is superior to CDJ, while the height reached is lower in the BDJ compared to CDJ.

Using BDJ or CDJ may ensue different adaptation to the training program. In fact, Young et al. (112) studied the effects of 6 weeks of training using DJs. The training group were asked to minimise the contact time with the floor improved the rate of force development compared with the control group. Therefore, it seems important to pay close attention to the execution technique during the training sessions with DJs. In agreement Toumi et al. (108) showed that subjects training with a higher velocity of stretch during the eccentric phase of squat training program to improve the vertical jump had a greater enhancement of jumped height during the CMJ compared to the group of subjects who use half this velocity during the stretching phase. Both groups of subject performed the concentric phase as quickly as possible (113).

The main challenge that plyometric training presents is to find out the most appropriate height from which to jump downwards. Between 40 and 62 cm has been reported as the optimal dropping height to attain the higher jumped height in the subsequent jump (46, 48). However, 20-40 cm is necessary to develop higher peak moment and power output in the reaction force in ankles and knees (17). According to Arteaga et al. (114) the optimal dropping height was 48.2 and 62.9 cm for females and males, respectively; while Lees and Fahmi (115) propose that the optimal height is 0.12 cm. Conversely, others studies did not find significant differences among groups that trained in a similar way but with different dropping heights from 0 to 100 cm (21, 116). This could explain why studies have used different heights (1). Moreover, Viitasalo et al. (117) have demonstrated that both neuromuscular function during DJ performance, as well as the response to the height from which subjects perform the DJs could vary in different groups of subjects. Therefore, it seems inappropriate to assume a general optimal dropping height when plyometric training is used as a training method. Further complicated by the fact that it remains unknown how to determine the optimal load for plyometric training.

Nevertheless, the use of DJ as exercise training presents several advantages, sophisticated material is not required, it doesn't consume a lot of training time and there are no lesion risks if it is executed correctly (1). Bobbert (1) proposes that the most effective and sure way to improve jump performance should begin with a training program that includes jumps in a regular way, followed by weight training and finally by a specific DJ training.

Potential mechanisms of adaptation to plyometric training

Plyometric training has been used in combination with other methods of training and some studies lack of an appropriate control group which precludes a definitive conclusion on the specific adaptations elicited by plyometric training alone. Cross-sectional data indicates that plyometric training may trigger muscle hypertrophy, particularly of type II fibers as observed in volleyball players (118). This could be related to the enhance recruitment of FT motor units during eccentric muscles contractions (119). Although SSC exercise training has been considered inappropriate to induce structural changes in muscle (120), a recent 8 week SSC-based training program showed otherwise (107). These authors administered an 8 week training program to a group of eight physically active men. This training program consisted of 24 sessions performed three times per week for a total of 5,228 jumps. All exercises were performed without overweight and included squat jumps (vertical jump starting with knees flexed at 90° without prior countermovement), vertical countermovement jump, drop jump (height of 40 cm), double-leg triple jump, single-leg triple jump (starting alternatively with left and right leg, final landing on two legs), double-leg hurdle jump (1 repetition =

5 hurdles), and single-leg hurdle jump (similar leg, 1 repetition = 5 hurdles). Both legs were loaded similarly during the one-leg exercises. Subjects were instructed to perform all jumps at a maximal effort and to amplify the knee flexion during the landing phase to maximise the eccentric component imposed to the knee extensors. With this training program vertical jump performances were increased by 9% (SJ) and 13% (CMJ). The authors determined the myosin isoform composition on 1,115 pre- and 1,002 post training fibers from the vastus lateralis muscle. The majority of muscle fibers contained MHC I, MHC IIa, or MHC IIa/IIx in pre- and posttraining samples. There was a tendency for an increased proportion of type IIa fibers (from 33 to 41%; P = 0.08) and a decreased percentage of type IIx fibers (from 7 to 3%; P = 0.06), but not all subjects responded in the same way to training. The total number of hybrid fibers (I/IIa, IIa/IIx, and I/IIa/IIx) was not altered (30 and 28%, respectively, before and after the training), while the proportion of type I/IIa fibers rose from 2 to 5%. The mean cross-sectional areas of type I, IIa, and IIa/IIx fibers were significantly increased with training by 23, 22, and 30%, respectively. These hypertrophies were associated with respective increases of 19, 15, and 16% in peak isometric tension, while the specific isometric tension (force/cross-sectional area) was not improved by training. Training enhanced the unloaded shortening velocity in all muscle fibers with type II fibers showing the greatest increase (+29% for type IIa fibers and +22% for type IIa/IIx fibers), whereas type I fibers displayed a smaller improvement (+18%). Peak power was also enhanced after training by 25% type I, 34% in type IIa and 49% in type IIa/IIx hybrid fibers (Fig. 4). However, normalised peak power, i.e. the product of specific tension and contraction velocity, was increased only for type IIa fibers (+9%). This training program also resulted in a higher stiffness of type IIa/IIx fibers (Fig. 5 and 6), without significant effects in the other fiber types. This is in agreement with the increase of the level of

eccentric muscle stiffness produced during CMJ increases with power training reported by Komi (121). In contrast, in rats SSC-training resulted in an increase in compliance of the series elastic component in rats (122, 123).

Increased muscle stiffness has the advantage of allowing greater storage and release of elastic energy (51, 121). A positive correlation has been described between rapid muscle force exertion characteristics (rate of force development) and connective tissue stiffness measured in vivo, as well as between maximal jumping height and the stiffness of the force-transmitting tissues (51). Isometric training has been associated with increased connective tissue stiffness (estimated by ultrasonography) and isometric rate of force development (124, 125) following a training intervention.

It has been suggested that other muscle adaptations could contribute also to increases power output during the concentric phase of a vertical jump following plyometric or eccentric training. These include neuromuscular adaptations such as the increased inhibition of antagonist muscles after training, better co-contraction or increased activation of synergistic muscles, reduction of neural inhibitory mechanisms, such as a Golgi tendon receptors discharge, and increased agonist motoneuron excitability and synchronisation (61, 108, 113, 126-133).

Weight training

Weight training is a strength training method based on lifting loads. This is likely the oldest type of strength training. It has been written that Milos of Crotona carried on his shoulders a young calf every day until the animal reached the 4 years to improve his strength (134). Weight lifting training can elicit a remarkable increase of maximal dynamic strength as reflected by the 2-2.5-fold elevation of the 1RM just with 8 weeks of training in subjects without strength training background (135). Interestingly, the effect elicited by the same training program applied to the same muscle groups shows movement specificity, with the highest improvements observed in the leg press and half squat exercises compared to the leg extension (135). Despite the efficiency for weight lifting training to increase 1RM performance of the muscles of the lower extremity, the effect of this methods to enhance vertical jump performance is limited to in most cases to 5-18% (Table II) (24, 103, 104). Although a more explosive lifting is supposed to be more effective than a heavier but slower one (103) to improve vertical jump performance, some controversy remains(28). Two main types of weight training have been applied to enhance vertical jump performance: heavy and light load (or ballistic) weight training.

Heavy load weight training

Heavy load weight training is generally seen as traditional weight training. In this training method loads of 80-100% of 1RM are lifted 1-8 times. This training method increases muscle strength by eliciting muscle hypertrophy but also by neural mechanisms (136-138). In addition, training with heavy load may also enhance the speed of movements leading to a marked improvement of peak (28) probably because it improves maximal force. However, weight training with short recovery periods between series, as a circuit training, appears much less efficient to enhance vertical jump performance (27).

Ballistic weight lifting training

Ballistic weight lifting training has been adapted to incorporate more dynamic and explosive movements to promote power development. It is known that when a subject performs a normal weight training exercise such as a squat, the bar must be stopped at the end of the range of movement. As a result, if light loads are used large accelerations are achieved at the beginning of the concentric phase of the movement; consequently the bar must be decelerated at the end of the movement. Elliott et al. (139) calculated that the deceleration phase accounted for 24% of the concentric phase of the bench press when using a maximal load. The deceleration phase increased to 52% when the bench press was performed at 81% of maximum load (139). Therefore, when performing traditional weight lifting training exercises at relatively light loads, the major part of the time is spent decelerating the load. This problem can be avoided if weighted jump squat training are used, because it permits the subject to accelerate all the way through the movement (explosive movement); this kind of training has been called “ballistic training” by Newton and Kraemer (140). This method has elicited improvements in elite (26) and non elite subjects (39, 103, 110). Similarly, Newton et al. (26) have shown that 8 weeks of ballistic training improved the vertical jump in elite volleyball players. The latter effect was associated to improvements in force, velocity, power output, and rate of force development during jumping on a force plate.

Maximal power training

This method maximises the mechanical power output, lifting the appropriate load to elicit maximal mechanic power during the lifting movement. According to the Hill model of muscle contraction and several *in vitro* experiments maximal power during dynamic contraction is usually achieved with a load close to 30% of the maximal isometric force (141, 142). Training with this level of resistance have been found to be very effective to improve mechanical power in movements that require explosiveness (39, 103, 143). Several studies have demonstrated that higher increments in peak power and vertical jump performance are achieved when the training is carried out with light loads (30-40% of the 1RM) and the movements executed at the maximum speed (39, 103, 141). Wilson et al. (103) showed that the group that trained with the load that maximised mechanical power achieved the best overall results in enhancing dynamic athletic performance and produced significantly better results, compared to the traditional weight training or plyometric training, on the jumping and isokinetic tests. However, Lyttle et al. (39) observed that both maximal power training and combined weight and plyometric training have similar effects on jumping performance. But, the combination of weight lifting with plyometric exercises yielded better results when subjects had to perform SSC activities. This may be caused by the fact that plyometric training is more dynamic than maximal power training and hence may better facilitate the neural and mechanical mechanisms that enhance performance in SSC activities.

Combined weight lifting training and plyometric training

Jumping height performance depends on take off velocity which is determined by the ability of muscles to both achieve a high level of force in a rather short time, i.e. to contract at high speed. The combination of weight lifting training with plyometric exercises aims at taken advantage of the enhancement of maximal dynamic force through weight lifting (135) and the positive effects of plyometric training on speed and force of muscle contraction through its specific effect on type II fibers (51). Weight lifting training alone could have a moderate positive effect on power if muscle contraction velocity is not improved or, even worse, reduced. Wilson et al. (42, 144) showed that weight training facilitates principally the concentric performance, whereas plyometric training emphasizes the eccentric component and the rate of force development. Thus, a combination of weight lifting and plyometric training would be a better training strategy to enhance power than either weight lifting or plyometric training alone. As we have described above weight lifting and plyometric training are effective in improving jumping performance, and so does the combination of plyometric and weight lifting training (Table III) (39, 104, 145, 146), despite some reports showing otherwise (105). Fatouros et al. (146) reported that the combination of weight lifting and plyometric training produced greater improvements in vertical jump performance and leg strength than either of the trainings regimes alone. In this study, the subjects trained using plyometric exercises 180 minutes before the weight training in order to perform the appropriate technique of the plyometric exercises. These authors think that it is important to allow for enough rest between sessions to recover the neuromuscular and metabolic capacities.

Blakey and Southard (147) observed that the participants in an 8-week combined program of plyometrics and weight lifting training improved leg strength and power. Lyttle et al. (39) found a similar effect using a combination of heavy resistance training and plyometrics or a ballistic resistance training. In the latter case, both protocols were similarly effective likely due to the fact that their subjects had never completed any explosive-type training and therefore both training methods represented a novel stimulus to their neuromuscular system.

Complex training

Complex training is a training strategy that combines heavy weight training and plyometric training in the same training session (148). This training method alternates similar weight training exercises of high loads, set for set, in the same workout prior to doing specific plyometric exercises to improve dynamic movement. In complex training subjects may perform a set of squats followed by a set of drop jumps. When two biomechanically similar exercises, one consisting in heavy weight lifting and the other in plyometric exercises (squat jumps, for example), are performed sequentially the training routine is called “complex pair” (92, 149). It has been suggested that this training method has an acute ergogenic effect on power and improves the jumping performance (150-152), because it may elicit post-activation potentiation (61). For example, the height reached during loaded countermovement jumps performed after a set of half squat at 5-RM was significantly higher (2.8%) than the same loaded countermovement jumps executed immediately preceding the half-squats (98). This effect may be observed more easily in subjects with a high level of strength. Chiu et al. (94) reported that strength-trained subjects enhanced their power performance for 5 to 18.5 minutes, while recreationally trained individuals showed fatigue in the following 5 minutes after heavy weight lifting training.

Zepeda and Gonzalez (153) observed that similar gains in strength and endurance were obtained in female athletes using either strength or complex training. This study give also support to the idea that complex training is more effective in highly trained subjects (154), maybe because they need a new strategy of training to improve power (149).

To optimise jumping performance it has been recommended to leave a recovery period of three to four minutes after the heavy weight lifts and the start of the plyometric sets (149). With shorter recovery the putative effect of post-activation potentiation may be mask by the fatigue caused by the precedent weight lifting exercises (61). However, despite leaving a recovery period of three minutes after the heavy resistant exercise Jones and Lees did not find a clear acute potentiating effect on power output with the complex training strategy (155). Similar discouraging results were reported by Duthie et al. (96) and Scott and Docherty (156).

It has been recently proposed to combine agonist and antagonist muscle exercises into the same power training session to elicit an acute increase in power output in the agonist power exercise (157). These authors studied a group of twenty-four college-aged rugby league players who were experienced in combined strength and power training who were randomly assigned to an experimental (Antag) or control (Con) group. The outcome variable was power output assessed during bench press throws with a 40-kg resistance with the Plyometric Power System training device. After warming up, the Con group performed the bench press throws tests 3 minutes apart to determine if any acute augmentation to power output could occur without intervention. The Antag group also performed the bench press throws before and after a set of bench pulls (the antagonistic action to the bench throw). Although the power output for the Con group remained unaltered between the two tests it was increased by 4.7% in the Antag group (157). Thus, combination of agonist and antagonist exercises may acutely increase power output during complex power training. However, it remains to be determined if such a strategy may lead to a greater adaptation when used systematically during the training sessions.

Although recommended by many in the training field, there is not enough scientific evidence as to defend that “complex training methods” are superior in developing vertical jump performance than for example the combination of weight lifting with plyometric training in different sessions.

Whole-body vibration treatment

Whole body vibration (WBV) is another training method used to improve vertical jump performance. The vibration is an oscillatory motion that involves biomechanical and physiological processes that could improve muscle strength and power. The most common form of whole body vibration is performed with the subject standing on a platform that generates a vertical sinusoidal vibration at a frequency, generally, between 25 and 40 Hz. The intensity of the vibration is determined by the amplitude of the vibration (the displacement of the oscillatory action, measured in mm), the frequency of the vibration and the acceleration of the vibration (considered in g that represent the Earth's gravitational).

Some authors have found an increase in vertical jump performance with the use of WBV (Table IV) (35, 36, 158-160) while other did not see such an effect (161-163). Delecluse et al. (158) reported that WBV three times per week during 12 weeks, elicited a 7.6% increases in CMJ in untrained female, who also improved isometric (16.6 %) and dynamic knee-extensor strength (9.0 %), although no effect on the maximal speed movement was achieved. Torvinen et al. (36) concluded that four-month vibration training induced an 8.5% improvement in the vertical jump performance which was accompanied by an enhancement of lower leg maximal isometric extension strength 3.7%. Bosco et al. (33) studied the effects of 10 times vibrations for a duration of 60 seconds with 60 s rest between each set in elite female volleyball players. They concluded that the significant enhancement in the average velocity, the average force, and the average power could be caused by neural adaptations. A similar treatments were applied in international-level boxers in arm flexor muscles and the results confirmed the enhancement of muscle power (164). In a follow up study, Bosco et al. (159) evaluated the endocrine and neuromuscular performance response to WBV. Their results revealed a significant increase in jumping performance and mechanical power output of the leg extensor muscles associated to a reduction in the root mean square electromyogram. During this period basal testosterone and growth hormone plasma concentrations increased while cortisol decreased.

In contrast, De Ruiter et al. (162) reported that 11 weeks of WBV training did not improve countermovement jump performance and functional knee extensor muscle strength in young (female and male) subjects. Similarly, Torvinen et al. (161) observed that an stimulus of 4 min of vibration was not sufficient to enhance the performance in several tests including vertical jump.

The mechanism by which WBV could improve jumping ability is not clear and more research is required to clarify and elucidate the use of WBV as a training method.

Electromyoestimulation training

Electromyostimulation (EMS) have been used mainly in rehabilitation (29, 165), but it has also been used in combination with strength training to enhance muscle adaptation and performance in different sports (166, 167), even in skills like vertical jump (Table V) (30, 31, 168). Maffiuletti et al. (30) observed a significant 14% increase in SJ performance after 4-weeks, 3 times a week, electromyostimulation program of the knee extensors of 10 basketball players. The improvement in vertical jump was accompanied by a significant increase in isokinetic strength at high velocities (between 180 and 360º x s^{-1}) and in isometric strength at the angles adjacent to the training angle. At week 8, gains in isometric, isokinetic and SJ performance were maintained and the CMJ increased significantly. A similar study was carried out on volleyball players (39). The EMS combined with plyometric training improved SJ (21%) and CMJ (9%) in volleyball players; in this case, there were an augmentation of the knee extensors and plantar flexors maximal strength at week 2. The significant increases in maximal and explosive strength were maintained after 2 additional weeks of volleyball training. In contrast, using the same types of athletes, Malatesta et al., (168) found no increases in SJ and CMJ after 4 weeks of EMS in spite of a significant increase in the mean height and the power during a test consisting on 15 seconds of consecutive CMJs (4%). However, jumped height increased significantly in SJ (6.5%) and CMJ (5.4%) ten days after the end of EMS training only after additional standardized basketball training.

The lack of appropriate control groups and lack of muscle biopsies to analyse the structural changes induced by the electrical stimulation programs preclude any definitive conclusion about the efficiency of EMS beyond that attainable with standard strength training methods.

Conclusion

Vertical jump performance is important for success in many sports and may used a test to assess muscle power. Several training methods have been used it to improve vertical jump performance, but the most commonly used are plyometric and weight lifting training methods. More recently whole body vibration and some forms of electromyostimulation have also been applied to improve vertical jump performance. It is not clear which is the best training method, although scientific evidence points to a combination of plyometric with weight lifting exercises. Plyometric training enhances muscular force, the rate of force developments, muscular power and muscle contraction velocity. These effects have been shown in children, physically active subjects and elite athletes. It has been shown that plyometric training enhances the mean cross-sectional areas of type I, IIa, and IIa/IIx, the unloaded shortening velocity and peak power in all muscle fibers with type II fibers showing the greatest imrpovement, without a significant enhancement of the specific isometric tension (force/cross-sectional area). Plyometric training may also enhance muscle stiffness allowing greater storage and release of elastic energy. Although irrefutable experimental evidence is lacking, it has been suggested that plyometric training may also elicit increased inhibition of antagonist muscles after training, better co-contraction or increased activation of synergistic muscles, reduction of neural inhibitory mechanisms and increased agonist motoneuron excitability and synchronisation. Ballistic weight training has also been associated to improvements in force, velocity, power output, and rate of force development during jumping on a force plate. It seems that the best results may be achieved through the combination of weight lifting and plyometric exercises.

Nevertheless, coaches should choose the most adequate method base on the situations, materials, time for training, economic possibilities and other factors. There are still many questions that need to be resolved, especially in regard with the physiological mechanisms that explain the results obtained with specific training protocols. It is particularly important is to unravel how different training routines may act on the regulation of gene expression, what kind of neuromuscular adaptation may be elicited, and how should these training programs be inserted in the busy schedule of the elite athletes. Application of further research could aid with the development of criteria to chose the appropriate training loads and how to combine methods in the most efficient way require additional research effort.

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Figure legends

Figure 1. The regulatory light chain of myosin is phosphorylated in striated muscles by Ca^{2+}/calmodulin-dependent (Ca^{2+}/CaM) myosin light chain kinase (MLCK). Unique biochemical and cellular properties of this phosphorylation system is that the fast-twitch skeletal muscle maintains the regulatory light chain of myosin in the phosphorylated form for a prolonged period after a brief tetanus or during low-frequency repetitive stimulation (From Sweeney et al. ref 79).

Figure 2. Force-pCa relationship for fully phosphorylated and fully dephosphorylated fibers (From Szczesna et al. ref 76).

Figure 3. Schematic representation of the mechanism proposed by Yang et al. (85) to explain how phosphorylation of myosin regulatory light chain induces conformational changes in the myosin cross bridge. Depicted is hypothetical average position of myosin cross bridge before and after regulatory light chain phosphorylation, relative to thin actin filament and thick (myosin) filament backbone. Dotted representations of cross bridges represent other possible cross-bridge positions. Yang et al. (85) hypothesized that light chain phosphorylation moves the average position of cross bridge away from thick filament, increasing rate at which it can attach to actin. This conformational change induced by phosphorylation could explain both increased force and rate of force development that has been observed to accompany phosphorylation in mammalian striated muscle. $PP\text{-}1_M$, myofribrillar form of protein phosphatase type 1. MLCK: myosin light chain kinase; Cam: calmodulin.

Figure 4. Shortening velocity and power as a function of fiber force in samples expressing type I (A), type IIa (B), or type IIa/IIx fibers (C). Data represent the average curves of all fibers before (Pre) and after (Post) 8 wk of stretch-shortening cycle exercise training (plyometric training). The specific curve of each fiber was determined by Malisoux et al. using the parameters of the fitted force-velocity relationship (From reference 107).

Figure 5. Progressive stretch experiments performed by Malisoux et al. in single muscle fibers pre and post stretch-shortening cycle exercise training (plyometric training) (107). A: fiber was progressively stretched from 76 to 140% of initial FL (sarcomere length of 2.5 µm) and then released again to 76% using a step duration of 3 min. Force change of passive force with respect to the value recorded at 76% of initial fiber length. B: passive tension was taken as the force recorded at the end of each step divided by fiber cross-sectional area and expressed as the change compared with the value at 76% of initial FL. Fiber strain was defined as any given FL divided by FL at 76% of initial length minus one. The ascending limb of the passive tension-fiber strain relationship () was used to determine complex Young's modulus (*E*) according to $y = E \bullet x^2$ (solid line). The data displayed were acquired from a fiber containing MHC I, and the complex Young's modulus value was 20.44 kN/m^2 (From reference 107).

Figure 6. Complex Young's modulus in type I, IIa, and IIa/IIx fibers before (Pre; n = 22, 35, and 17, respectively) and after (Post; n = 20, 39, and 12, respectively) 8 wk of stretch-shortening cycle exercise training (plyometric training), determined by Malisoux et al (107). *Significant differences between pre- and posttraining fibers containing similar MHC isoforms ($P < 0.05$). Due to lack of data, fiber types I/IIa and IIx were not analised in that study.

Table I. Results from plyometric training (PT) and its effect on improvements on the vertical jump..

References	Training		Intensity Drop (cm)	Weeks	Sessions per Week	Sets	Rep	N	Gender	Subject	Age Yr	Jumps total	Jumps per sessions	Gain								
														cm				%				VJ cm
														SJ	CMJ	DJ	Hands	SJ	CMJ	DJ	Hands	
Bauer et al. (145)	PT			10	3			8	M-F	Student	23											2.7
Adams et al. (104)	PT	DJ	51-114	6	2				M	Trained												3.8
		SJ		6	2				M	Trained												
Wilson wt al. (103)	PT	DJ	20-80	10	2	3-6		13	M	Trained	22				3.7				10.3			
Gehri et al. (106)	PT	CMJ		12=(2+10)	2	2-4	8	7	M-F	Student	19	352	16-32	1.9	1.7	2.4		6.8	5.4	8.7		
		DJ	40					11			20			3.3	2.1	2.8		13.6	8	10.9		
Potteiger et al. (22)	PT							8	M	Active	21						2.7				4.6	
		DJ	40	6	3	1-8	4-10					274	4-8									
		SJ		8	3																	
	PT + AE							11	M	Active	21						3.1				5	
		DJ	40	6	3	1-8	4-10					274	4-8									
		SJ		8	3																	
Fatouros et al. (146)	PT + DE			12				11	M	Untrained	21	6160	80-220				6				11.3	
		DJ	30-80	6	3																	
		SJ		12	3																	
Diallo et al. (18)	DJ + DE		30-40	10=(5+5)	3			20		Boys	12	7500	200-300	2	3.4			7.3	11.6			
Matavulj et al. (21)	PT	DJ	50	6	3	3	10	22	M	Elite	15.5	540	30		4.8							
			100												5.6							
Toumi et al. (108)	ISO	0.4		8	4	6	10	12	M		19-23			2.9	5.2							
		0.2		8	4	6	10	12	M		19-22			3.4	3.5							
Malisoux et al. (107)	PT	DJ	40	8	3			8	M	Active	23	5228		3	6			9	13			
Kotzamanidis (111)	PT	DJ	10-30	10	2			30	M	Boys	11	1580	60-100	8								

Repetitions (Rep); Number of subjects (N); Squat jump (SJ); Countermovement jump (CMJ); Drop jump (DJ); Jump and reach technique (Hands); Vertical jump (VJ); Male (M); Female (F); Aerobic exercise (AE); Dynamic exercises (DE); Isokinetic ergometer (ISO).

Table II. Results from weight lifting (WL) and its effect on improvements on the vertical jump.

Referentes	Training	Intensity		Weeks	Sessions per Week	Sets	Rep	N	Gender	Subject	Age Yr	Gain								
												in cm				in %				VJ cm
		%RM	RM									SJ	CMJ	DJ	Hands	SJ	CMJ	DJ	Hands	
Bauer et al. (145)	WL	60		10				8	M-F	Student	22									4.5
Adams et al. (104)	WL	50-100		6	2	1-4	2-8		M	Trained										3.3
Wilson et al. (103)	WL		6-10	10	2	3-6	6-10	15	M	Trained	22	2	1.9			6.8	5.1			
	MP	30		10	2	3-6		13	M	Trained	24	5	6			15	18			
Baker et al. (23)	NPM		6-8	12	3	5-3		9	M	Experienced	19				4.5					
	LPM		10-1	12	3	5-3		8	M	Experienced	20				2					
	UPM		10-3	12	3	5-3		5	M	Experienced	21				4.9					
Lyttle et al. (39)	MP	30		8	2	2-6	8		M	No experience		7	3.8			20	7.8			
Newton et al. (26)	BA	30-60-80		8	2	6	6	16	M	Elite	19				3.9				5.9	
Fatouros et al. (146)	WL	70-95		12=(8+4)	3	7		10	M	Untrained	21				5.4				9.3	
Harris et al. (25)	HF	80-85		9	4	5	5	13	M	Trained	19									
	HP	30% MIF		9	4	5	5	16	M	Trained	19									2.3
	HF + HP			9	4	5	5	13	M	Trained	20									1.8

Percent of maximum load (%RM); Repetition maximum load (RM); Repetitions (Rep); Number of subjects (N); years (yr); Squat jump (SJ); Countermovement jump (CMJ); Drop jump (DJ); Jump and reach technique (Hands); Vertical jump (VJ); Male (M); Female (F); Traditional weight training (WL); Maximal power training (MP); Non periodized methods (NPM); Linear periodized method (LPM); Undulating periodized method (UPM); Ballistic training (BA); High force (HF); High power (HP); Maximum isometric force (MIF).

Table III. Results from Plyometric training (PT) and weight lifting (WL) and their effects on improvements on the vertical jump.

References	Training	Weeks	Sessions per Week	Sets	Rep	N	Gender	Subject	Age	Gain								
										In Cm				In %				VJ cm
									Yr	SJ	CMJ	DJ	Hands	SJ	CMJ	DJ	Hands	
Bauer et al. (145)	PT + WL	10	3			7	M-F	Student										4.1
Adams et al. (104)	PT + WL	6	2				M	Trained										11
Lyttle et al. (39)	PT + WL	8	2				M	No experience		7	5.6			19	13			
Fatouros et al. (146)	PT + WL	12	3			10	M	Untrained	20				8.6				14.6	

Repetitions (Rep); Number of subjects (N); years (yr); Squat jump (SJ); Countermovement jump (CMJ); Drop jump (DJ); Jump and reach technique (hands); Vertical jump (VJ); Male (M); Female (F).

Table IV. Results from Whole-body vibration (WBV) and its effect on improvements on the vertical jump.

Referentes	Training	Intensity vibration			Weeks	Sessions per Week	Sets	Volume vibration		N	Gender	Subject	Age Yr	Acceleration of the platform	Gain							
		Amplitude mm	Frequency Hz	Rest				Duration							in Cm				in %			
								Without rest	One session						SJ	CMJ	DJ	Hands	SJ	CMJ	DJ	Hands
Bosco et al. (159)	WBV	4	26	6'	10 times		5--5	60 s		14	M	Active	25	17 g		1.4				3.9		
Torvinen et al. (36)	WBV	2	25-40		4 month	3—5			4'	26	F-M	Nonathletic	23	2.5-6.4 g		2.5				8.5		
Delecluse et al. (158)	WBV	2.5-5	35-40	60-5 s	12	3	1--3	30-60 s	3-20'	18	F	Untrained	21	2.28-5.09 g						7.6		

Rest between exercise (Rest); Repetitions (Rep); Number of subjects (N); years (yr); Squat jump (SJ); Countermovement jump (CMJ); Drop jump (DJ); Jump and reach technique (hands); Male (M); Female (F); Physically active (Active).

Table V. Results from Electromyostimulation (EMS) and its effect on improvements on the vertical jump.

References	Training	Intensity mA	Weeks	Sessions per Week	Sets	Pulse		Contractions per sessions	Treat-ment time	N	Gender	Subject	Age Yr	Gain									Gain after in %	
						Rate Frecuency	Width Duration							in cm				in %						
														SJ	CMJ	DJ	Hands	SJ	CMJ	CMJs	DJ	Hands	SJ	CMJ
Maffiuletti et.al (30)	EMS + BB	0-100	4	3	12	100 Hz	0.4 s	48	16'	10	M	Basketball	25					14						17
Maffiuletti et.al (40)	EMS + PT	60-120	4	3		115-120 Hz	0.4 s	48	16'	10	M	Volleyball	22					21						
Malatesta et al. (168)	EMS	0-100	4	3		105-120 Hz	0.4 s	20-22	12'	12	M	Volleyball	17							3.8			7	5.4

Number of subjects (N); years (yr); Squat jump (SJ); Countermovement jump (CMJ); 15 seconds of consecutive CMJ (CMJs); Drop jump (DJ); Jump and reach technique (hands); Male (M); Female (F); Basketball session (BB); Plyometric training (PT); Gain after training program (Gain after).

Fig 1.

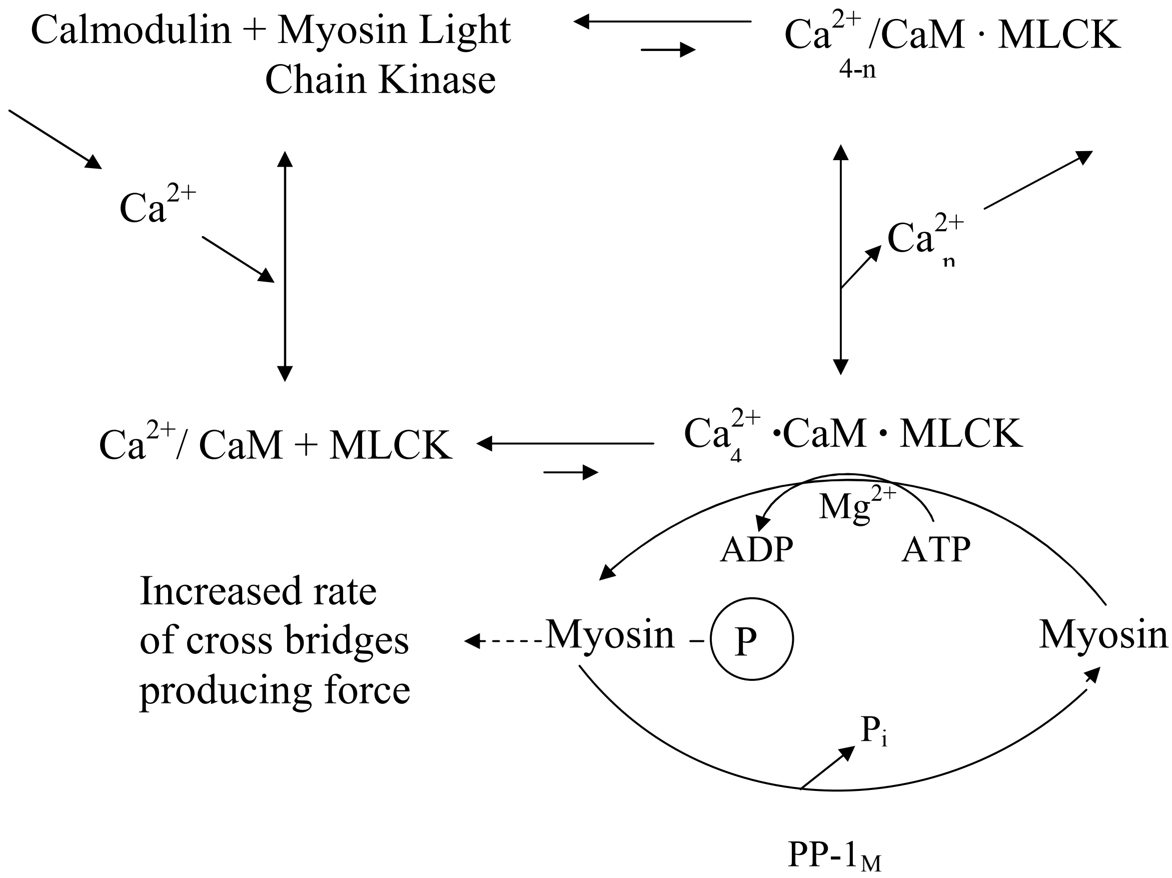

Calmodulin + Myosin Light Chain Kinase
Ca2+4-n/CaM · MLCK
Ca2+
Ca2+n
Ca2+/ CaM + MLCK
Ca2+4 ·CaM · MLCK
Mg2+
ADP
ATP
Increased rate of cross bridges producing force
Myosin – P
Myosin
Pi
PP-1M

Fig. 2.

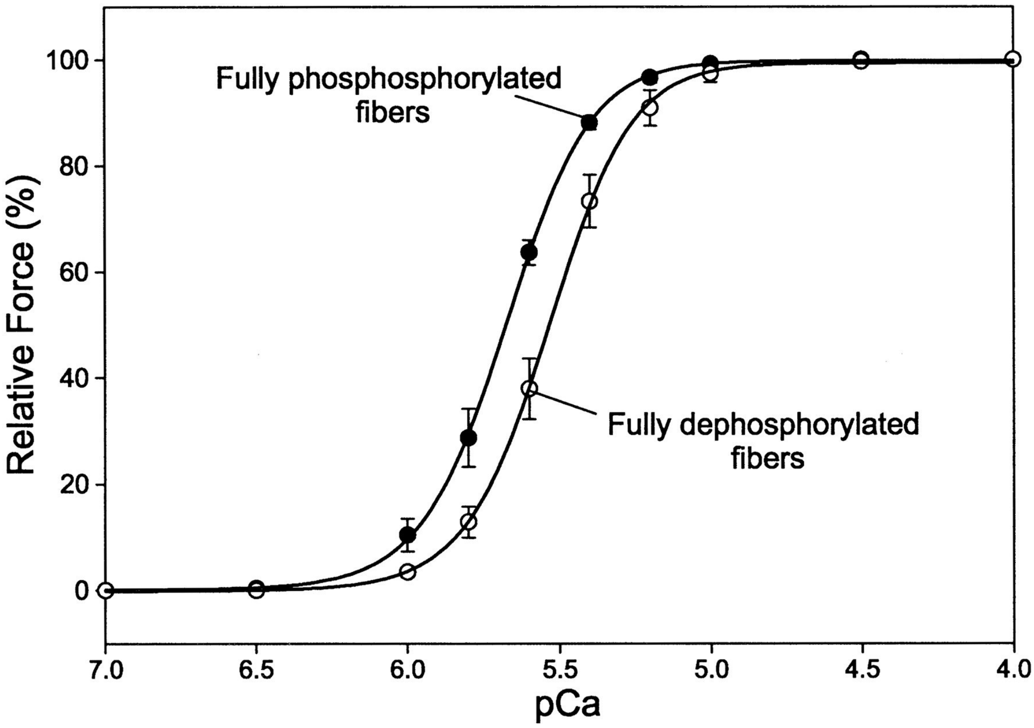

Fully phosphosphorylated
fibers
Fully dephosphorylated
fibers
Relative Force (%)
0
20
40
60
80
100
7.0
6.5
6.0
5.5
5.0
4.5
4.0
pCa

Fig. 3

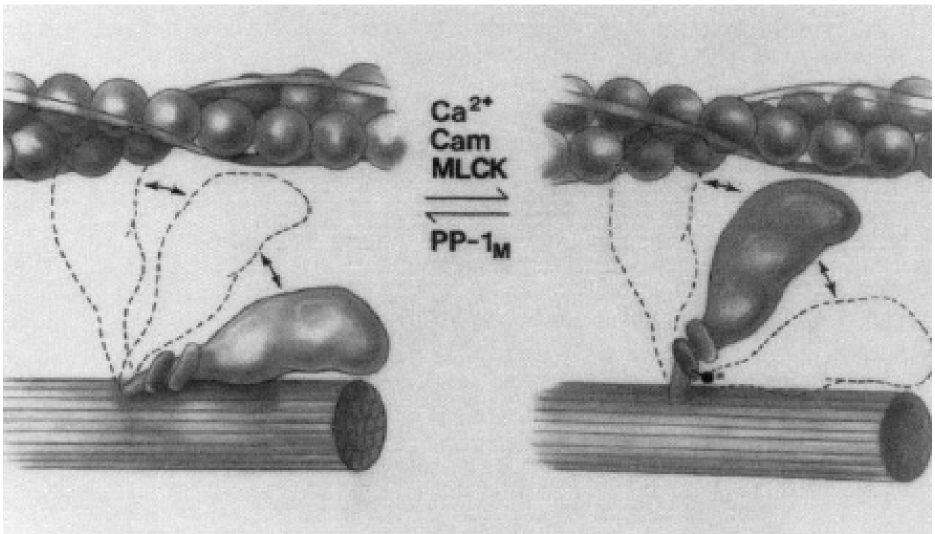


Fig 4.

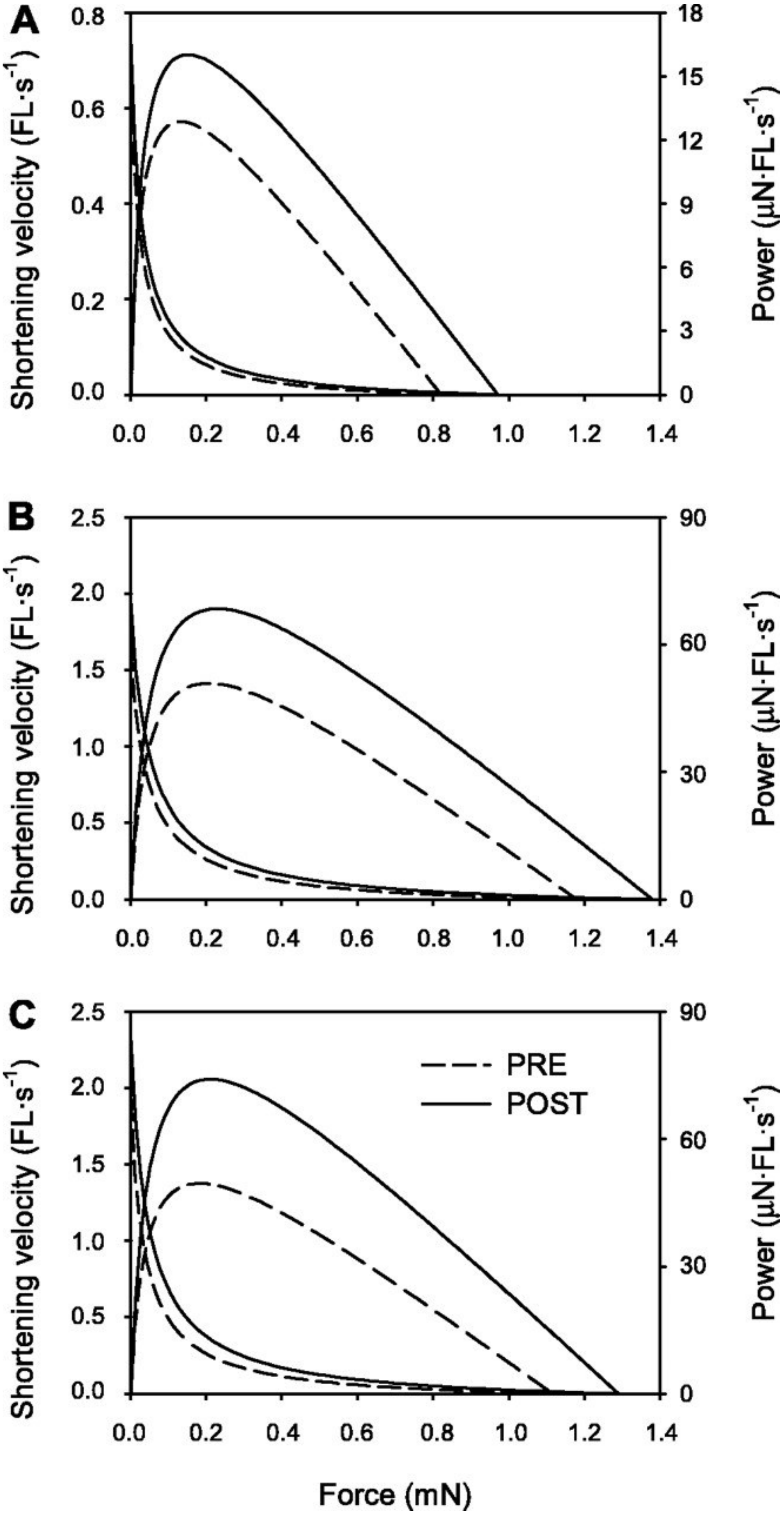
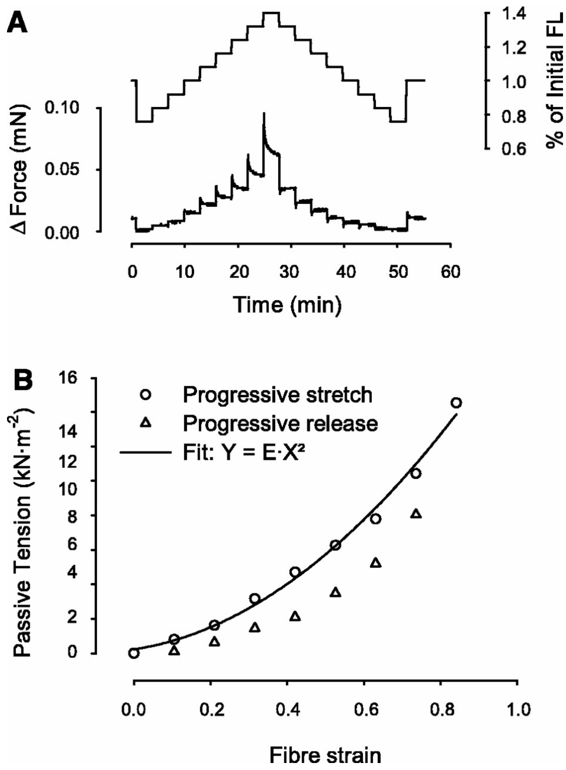

A
B
C
Shortening velocity (FL·s-1)
Power (µN·FL·s-1)
0.0
0.2
0.4
0.6
0.8
0
3
6
9
12
15
18
0.5
1.0
1.5
2.0
2.5
30
60
90
1.2
1.4
PRE
POST
Force (mN)

Fig 5.


A
Δ Force (mN)
0.10
0.05
0.00
% of Initial FL
1.4
1.2
1.0
0.8
0.6
0
10
20
30
40
50
60
Time (min)
B
Passive Tension (kN·m-2)
16
14
12
10
8
6
4
2
0
Progressive stretch
Progressive release
Fit: Y = E·X²
0.0
0.2
0.4
0.6
0.8
1.0
Fibre strain

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TRAINING AND TESTING THE ELITE ATHLETE

Jens Bangsbo, Magni Mohr, Allan Poulsen, Jorge Perez-Gomez, Peter Krustrup

Copenhagen Muscle Research Centre, Institute of Exercise and Sport Sciences, August Krogh Institute, University of Copenhagen, Copenhagen, DENMARK

The performance of a top-class athlete can be improved by appropriate training. The fitness training should be closely related to the activities of the athlete during competition. Furthermore, the capacity of the athlete should be known. For that purpose, Yo-Yo tests can be used since they have been shown to be sensitive and to give valid measures of performance in many sports. The fitness training can be divided into aerobic, anaerobic and specific muscle training. Each type of training has a number of subcategories, which allows for a precise execution of the training when the aim of the training is known. A critical factor when training elite athletes is when to do what, i.e. to plan the training. An example of the preparation of the Danish National soccer team for the European Championship 2004 is given in the text with examples of physiological measurements and testing, which also takes individuals' needs into account.

Keywords: aerobic, anaerobic, heart rate, planning fitness training, training categories, Yo-Yo testing

Introduction

Performance of an athlete in top-sport depends on the athlete's technical, tactical, physiological, and psychological/social characteristics (Figure 1). These elements are closely linked to each other, e.g., the technical quality of an athlete may not be utilized if the athlete's tactical knowledge is low. The physical demands in a sport are related to the activities of the athlete. In some sports, continuous exercise is performed with either a very high (e.g., 400-m run) or moderate intensity (e.g., marathon run) during the entire event. In other sports, like soccer and basketball, athletes perform different types of exercise ranging from standing still to maximal running with varying intensity. Under optimal conditions, the demands in sport are closely related to the athlete's physical capacity, which can be divided into the following categories: (i) the ability to perform prolonged exercise (endurance); (ii) the ability to exercise at high intensity; (iii) the ability to sprint; and (iv) the ability to develop a high power output (force) in single actions during competition such as kicking in soccer and jumping in basketball (Figure 1). The performance within these categories is based on the characteristics of the respiratory and cardiovascular system as well as the muscles, combined with the interplay of the nervous system. The muscular system is constituted by a multitude of components, which have important influence on the mechanical and metabolic behavior of the muscle (Figure 1). Muscle morphology and architecture, and myosin isoform composition play a major role in the contractile strength characteristics of the muscle evaluated as maximal isometric, concentric, and eccentric contraction force, maximal rate of force development, and power generation. Glycolytic muscle enzyme levels and ionic transport

Corresponding Author
Jens Bangsbo, Institute of Exercise and Sport Sciences, The August Krogh Building, Universitetsparken 13, DK-2100, Copenhagen Ø, DENMARK.
Tel: (45) 353 21622
Fax: (45) 353 21600
E-mail: jbangsbo@aki.ku.dk

systems are major determinants of anaerobic muscle performance, both when expressed as anaerobic power and capacity. Likewise, mitochondrial enzyme levels and capillary density exert a strong influence on aerobic muscle performance in turn affecting the force development and the maximal power output of human skeletal muscle, while also influencing the endurance performance of the muscle fibers. The respiratory, cardiovascular, and muscle characteristics are determined by genetic factors but they can also be developed by training. A number of environmental factors such as temperature and for outdoor sports, the weather and the surface of

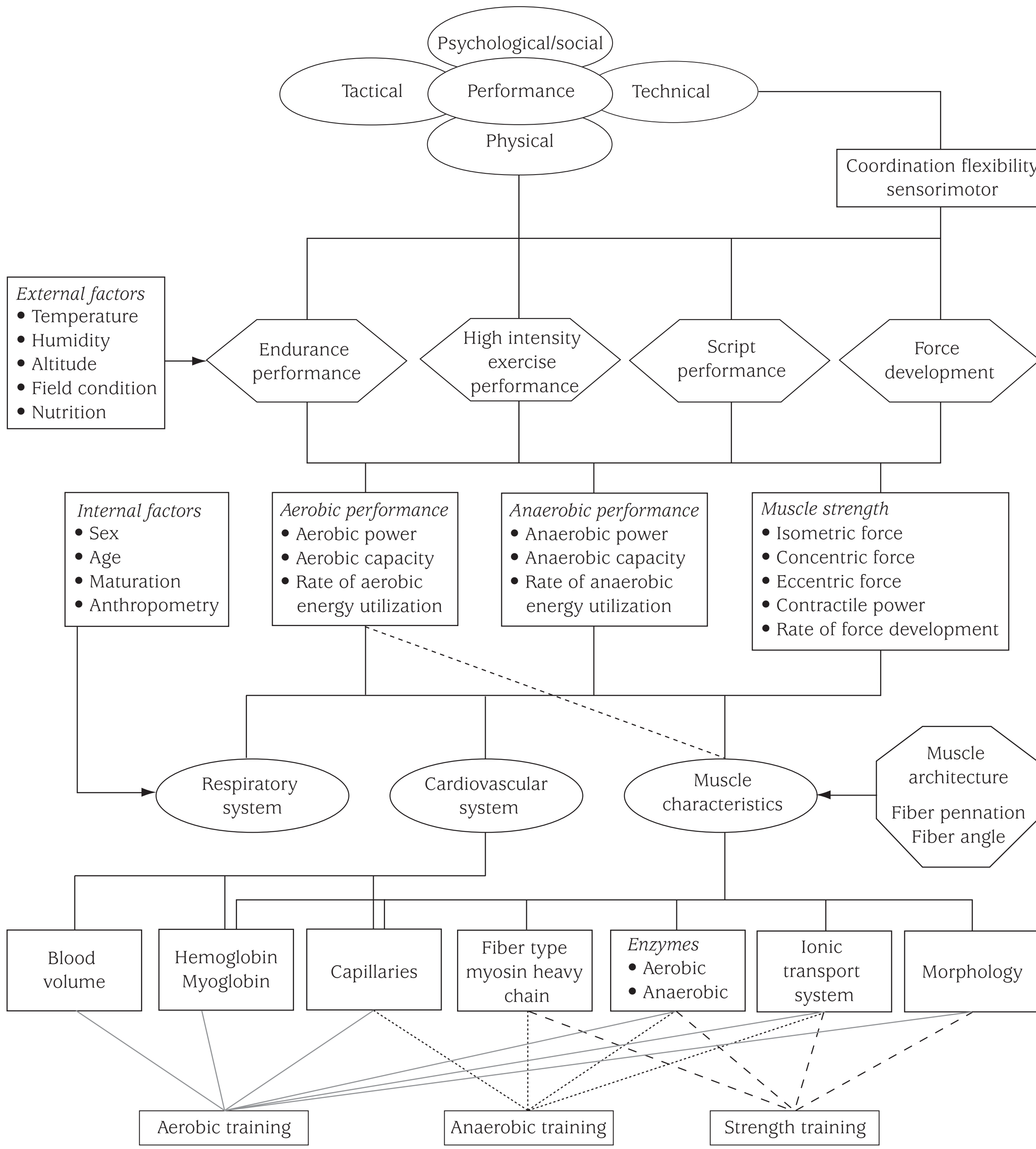

Fig. 1 A holistic model of the determinants of sports performance.

the competition ground also influence the demands of the athletes.

In some sports it is very important for the athlete to bear a very high physical capacity at least in one of the categories to perform at a top level, e.g., a marathon runner needs a high endurance capacity, but not a well-developed ability to produce a high power output in a single action. In other sports, such as team sports, an athlete may need an all-round fitness level. In such sports, an athlete with a moderate endurance capacity may to some extent compensate this weakness by having good capabilities in other areas relevant to the sport, e.g., a high technical standard or good sprinting ability.

In this article, the cardiovascular and muscular adaptations with regard to training or inactivity are addressed and the various components of fitness training are presented. The value of using field test to evaluate the performance of athletes is also described. Finally, how to prioritize the training of top athletes with a special emphasis on the preparation of the Danish National soccer team for the European Championship 2004 is discussed.

Evaluation of physical performance of an athlete

Competition naturally provides the best test for an athlete, but it is difficult to isolate the various components within the sport and get objective measures of performance. Fitness testing can provide relevant information about specific parts of a sport. Before selecting a test, clear objectives should be defined. The reasons for testing an athlete are outlined below:

- To study the effect of a training program
- To motivate the athletes to train more
- To give an athlete objective feedback
- To make an athlete more aware of the aims of the training
- To evaluate whether an athlete is ready to compete
- To determine the performance level of an athlete during a rehabilitation period
- To plan short- and long-term training programs
- To identify the weaknesses of an athlete

To obtain useful information from a test, it is important that the test is relevant and resembles the conditions of the sport in question. For example, a cycle test is of minor relevance for a swimmer. There are a number of commonly used laboratory tests, which evaluate the various aspects of performance (Figure 1). These include determination of maximum oxygen uptake to evaluate the athletes' ability to take up and utilize oxygen. A Wingate test, which consists of 30 s of maximal cycle exercise, aiming at determining the maximum anaerobic power and ability to maintain a high power output. Strength measurements in which the strength of an isolated muscle group is measured either during isometric, concentric, or eccentric contractions are also used as laboratory tests. Such tests provide general information about the capacity of an athlete and may separate the different performance levels of athletes within a sport. In some sport such general tests can provide information on the requirement of the sport, e.g., to be a top-class cross-country skier a maximum oxygen uptake higher than 80 mL min^{-1} kg^{-1} is required.

These classical laboratory tests may also be useful for comparisons of performance between various sports. However, to a minor extent, they may only express the performance of the athlete during competition. For example, Figure 2 shows that for 20 top-class soccer players there was no relationship between knee-extensor strength and kick performance, suggesting that the strength of the knee-extensors alone does not determine the final impact on the ball in a

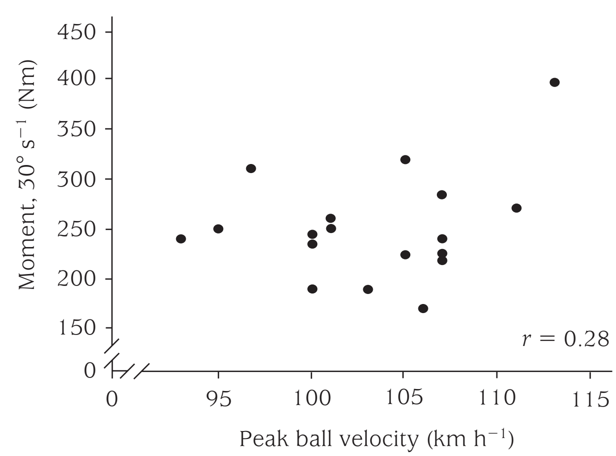

Fig. 2 Individual relationship between kick performance (peak ball velocity) and maximum knee extensor torque (Nm) under isokinetic loading at a velocity of 30 s^{-1} for elite soccer players.

kick. Strength of other muscle groups, such as the hip muscles, may be important and technical skill is also a predominant factor in the soccer kick, which incorporates a complex series of synergistic muscle movements, involving the antagonistic muscles as well. A test that is more specific to the sport will increase its validity, i.e., the test result reflects the better performance of an athlete. A number of examples of sport-specific tests that are simple to organize is described later in this article. Some of them require special equipment to simulate the activities in the sport while the others only need simple materials.

Rowing is characterized by a certain movement involving body muscles. A rowing ergometer is developed in which it is possible to simulate the movement in the boat. Performance can be evaluated by measuring the total work performed within a given time, e.g., 6 min as in some races, or the time it takes to get exhausted at a given external work rate. To obtain further information about the capacity of the oarsman tested, a number of physiological measurements can be added to the test such as pulmonary oxygen uptake wherein the rate of rise of oxygen uptake in the initial phase of exercise and the peak oxygen uptake during the rowing are determined. Undoubtedly such a test has a high validity.

One of the most widely used field test is the Cooper test, where the participants are made to run the longest possible distance in 12 min. Though it is simple to perform, it has the disadvantage that the athletes are required to know how to tactically perform the test to obtain the best test result. It also requires the distance to be least 200 m. Nevertheless, the popularity of the test is probably due to the fact that it is simple and a correlation between performance and VO_{2max} has been observed. However, the type of running in the test may only be relevant for track runners and they have anyway the simplest test, namely the competition. Further, the relationship between the test and $\dot{V}O_{2max}$ may not be very useful, since in many sports, such as ball games, $\dot{V}O_{2max}$ is a poor marker of physical performance during competition.

The Yo-Yo tests

The Yo-Yo tests are a number of tests which in an easy way evaluates various aspects of performance. The tests contain running activities that are relevant for many sports. With the tests, the physical capacity is evaluated in a fast and simple manner. Two markers are positioned at a distance of 20 m. A CD is placed in a CD player and the test is performed. The participant runs like a Yo-Yo back and forth between the markers at given speeds that are controlled by the CD. The speed is regularly increased, and the test ends when the individual can no longer maintain the speed. The test result is determined as the distance covered during the test. Using the Yo-Yo tests, it is possible to obtain information about a large number of athletes within a short time, and the tests have higher performance validity during competition than laboratory tests. There are three Yo-Yo tests. In one, called the Yo-Yo endurance test, the participants perform continuous exercise, and in the other two, the participants carry out intermittent exercise, namely the Yo-Yo intermittent endurance test and the Yo-Yo intermittent recovery test. The principles of the Yo-Yo intermittent test are similar to the continuous Yo-Yo tests, except that in the intermittent tests, the athletes have a period of active rest between each of the 2 × 20-m shuttles. The tests can be used by anyone, irrespective of training status, since each of the three tests has two levels.

The *Yo-Yo endurance test* lasts for 5–15 min and is used for the evaluation of the ability to work continuously for a longer period of time. This test is especially useful for individuals who participate in endurance exercise, such as distance running. The *Yo-Yo intermittent endurance test* lasts for 10–20 min and consists of 5–18 s intervals of running interspersed by regular 5-s rest periods. The test evaluates an individual's ability to repeatedly perform running intervals over a prolonged period of time. The test is especially useful for the athletes who perform interval sports such as tennis, team handball, basketball, and soccer. Figure 3 shows the performance of top-class basketball players. The *Yo-Yo intermittent recovery test* lasts for 2–15 min and focuses on the ability to recover after intense exercise. Between each exercise period (5–15 s) there is a 10-s pause. The test is particularly suitable for sports in which the ability to perform intensive exercise after short recovery periods can be decisive for the outcome of a competition such as badminton, soccer, basketball, ice-hockey, and football. The test is shown to have a high reproducibility, sensitivity, and validity for soccer (Krustrup et al. 2003).

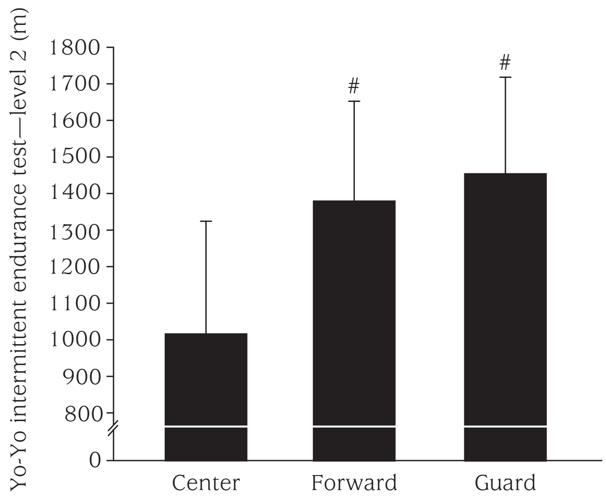

Fig. 3 Yo-Yo intermittent endurance level 2-test performance for elite basketball players at different playing positions. The # symbol denotes a significantly better performance for guards and forwards compared to center players.

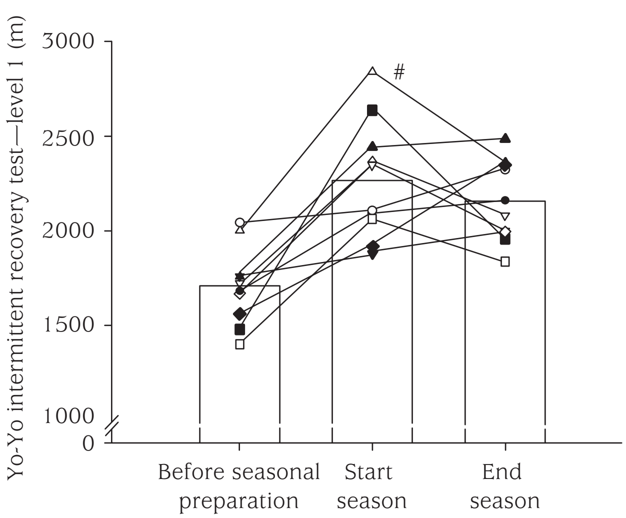

Fig. 4 Yo-Yo intermittent recovery level-1 test performance for 10 elite soccer players before the pre-seasonal preparation, at the start and end of the season. The # symbol denotes a significantly better performance at the start of the season compared to before the pre-seasonal preparation.

Thus, the test is able to pick up changes in performance as shown in Figure 4, where the performance of soccer players at various stages of a preparation period is given. Performance of the *Yo-Yo intermittent recovery test* (level 1) in the pre-season preparation of professional soccer players was improved by 31% with only a minor change in VO_{2max}.

It is also possible to perform the tests without exhausting the participants. Then the test is stopped after

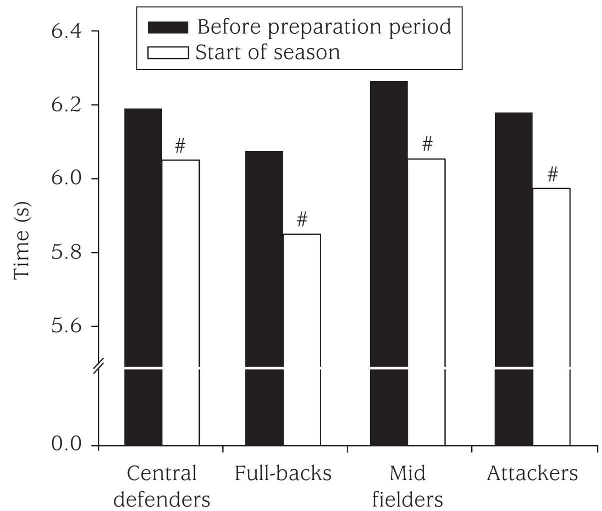

Fig. 5 Repeated sprint performance before and after the pre-seasonal preparation period of elite soccer players at various playing positions. The # symbol denotes a significant difference between the test before and after the pre-seasonal preparation period.

a given time and the heart rate is measured to evaluate the development of the cardiovascular system. The lower the heart rate the higher is the capacity of the individual. Thus, it has been observed that there is a relationship between heart rate after 6 min of the Yo-Yo intermittent endurance test (level 2) and the amount of high-intensity running during intense parts of matches for players in the Danish National Soccer team. Such nonexhaustive tests can be used frequently and is particularly useful for athletes who are in a rehabilitation period.

Repeated sprint test

The ability to be able to run fast and to do repeated sprints can be easily tested by having the athlete to sprint a given distance a number of times separated by a period of recovery that allow a decrease in performance. In relation to the latter aspect Balsom et al. (1992) observed that performance in a 30-m sprint could be maintained when subjects have a recovery period of 120 s between each sprint, but a marked decrease was found when the recovery time was 30 s. This means that in order to evaluate an athlete's ability to recover from intense exercise the rest period between 30-m sprints should be 30 s or shorter. In a test to measure the ability to sprint and at the same time change direction, athletes perform seven sprints each lasting about 7 s, separated by 25-s rest periods. Figure 5 shows how the performance of

25 professional soccer players changed during a preparation period. The significant decrease in the sprint time shows that the test can reveal changes in performance.

Fitness training

In many sports the athletes need a high level of fitness to cope with the physical demands of the competition and to allow for their tactical and technical skills to be utilized throughout the competition. Fitness training in any sport has to be focused on the demands in the sport and in many sports is has to be multifactorial to cover the different aspects of physical performance in the sport. Therefore, the exercise performed should, whenever it is possible, resemble the activities during competition as closely as possible.

It is useful to divide fitness training into a number of components related to the purpose of the training (Figure 6). The terms aerobic and anaerobic training are based on the energy pathway that dominates during the activity periods of the training session. Aerobic and anaerobic training represent exercise intensities below and above the maximum oxygen uptake, respectively. However, in some sport like ball games, in which the ball is used in the fitness training, the exercise intensity for an athlete varies continuously, and some overlap exists between the two categories of training (Bangsbo 2005). The separate components within fitness training are described briefly in the next few paragraphs.

Aerobic training

Aerobic training causes changes in central factors such as the heart and blood volume, which result in a higher maximum oxygen uptake (Ekblom 1969). A significant number of peripheral adaptations also occur with this type of training (Henriksson & Hickner 1996). The training leads to proliferation of capillaries and an elevation of the content of mitochondrial enzymes, as well as the activity of lactate dehydrogenase 1–2 (LDH_{1-2}) isozymes. Further, the mitochondrial volume and the capacity of one of the shuttle systems for NADH are elevated (Schantz & Sjoberg 1985). These changes cause marked alterations in muscle metabolism. The overall effects are an enhanced oxidation of lipids and sparing of glycogen, as well as a lowered lactate production, both at a given and at the same relative workrate (Henriksson & Hickner 1996).

The optimal way to train the central versus the peripheral factors is not the same. Maximum oxygen uptake is most effectively elevated by exercise intensities of 80–100% of VO_{2max}. For a muscle adaptation to occur, an extended period of training appears to be essential, and therefore, the mean intensity has to be $<80\%$ of VO_{2max} once in a while. This does not imply that high-intensity training does not elevate the number of capillaries and mitochondrial volume in the muscles engaged in the training, but the duration of this type of training is often too short to obtain optimal adaptations at a local level.

The dissociation between changes in VO_{2max} and muscle adaptation by means of training and detraining

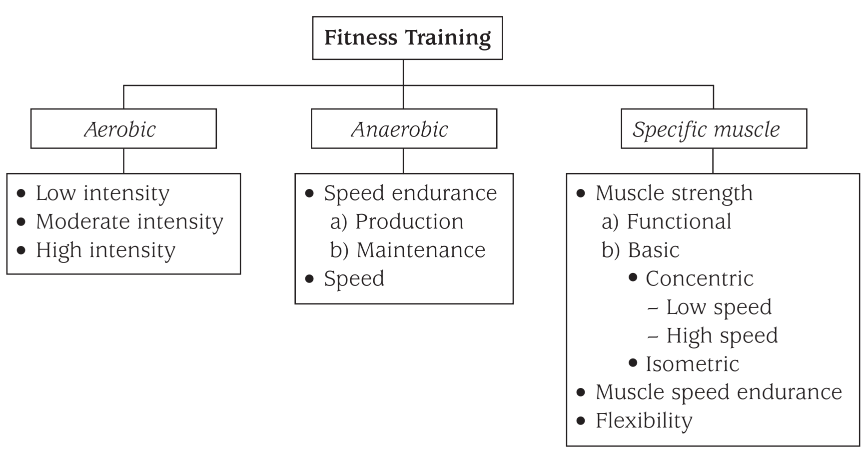

Fig. 6 Components of fitness training.

is illustrated by the results from the two studies. In one study, long-distance runners were kept inactive for 2 weeks (first week with the leg in a cast) which did not result in a change in VO_{2max} (Houston et al. 1979). On the other hand, the detraining period led to a 25% decrease in performance in an exhaustive run (from about 18 to 13.5 min) which was associated with a 24% lowering of the activity of succinate dehydrogenase (SDH). In the following 2 weeks of retraining, VO_{2max} did not change, whereas performance and SDH were lowered by 10% and 20%, respectively. The level of inactivity does not have to be as extreme as in this study to have a marked effect on performance and muscle respiratory capacity. In another study top-class soccer players abstained from training for 3 weeks (Bangsbo & Mizuno 1988). It was found that VO_{2max} was unaltered, whereas performance in a field test was lowered by 8%, and there was a reduction of 20–30% in oxidative enzymes.

The recovery processes from intense exercise are related both to the oxidative potential and to the number of capillaries in the muscles (Tesch & Wright 1983). Thus, aerobic training not only improves endurance performance of an athlete, but also appears to influence an athlete's ability to repeatedly perform to maximal efforts. The overall aim of aerobic training is to increase the work-rate during competition, and also in ball games to minimize a decrease in technical performance as well as lapses in concentration induced by fatigue towards the end of a game. The specific aims of aerobic training are as follows:

- To improve the capacity of the cardiovascular system to transport oxygen. Thus, a larger percentage of the energy required for intense exercise can be supplied aerobically, allowing an athlete to work at higher exercise intensity for prolonged periods of time
- To improve the capacity of muscles specifically used in the sport to utilize oxygen and to oxidize fat during prolonged periods of exercise. Thereby, the limited store of muscle glycogen is spared and an athlete can exercise at a higher intensity towards the end of a competition
- To improve the ability to recover after a period of high-intensity exercise in team sports. As a result, an athlete requires less time to recover before being able to perform in a subsequent period of high-intensity exercise

Components of aerobic training

Aerobic training can be divided into three overlapping components: aerobic low-intensity training ($Aerobic_{LI}$), aerobic moderate-intensity training ($Aerobic_{MO}$), and aerobic high-intensity training ($Aerobic_{HI}$; Figure 6). Table 1 shows the principles behind the various categories of aerobic training, which take into account that in some sports the training may be performed as a game, and thus, the heart rate of the athlete may frequently alternate during the training.

During $Aerobic_{LI}$ the athletes perform light physical activities, such as jogging and low-intensity games. This type of training may be carried out the day after a competition or the day after a hard training session to help the athlete to return to a normal physical state. $Aerobic_{LI}$ may also be used to avoid the athletes from getting into a condition known as "overtraining" in periods involving frequent training sessions and a busy competitive schedule.

The main purpose of $Aerobic_{MO}$ is to elevate the capillarization and the oxidative potential in the muscle (peripheral factors). Thus, the functional significance is an optimization of the substrate utilization and thereby an improvement in endurance capacity. The main aim of $Aerobic_{HI}$ is to improve central factors such as the pump capacity of the heart, which is closely related to VO_{2max}. These improvements increase an athlete's capability to exercise repeatedly at high intensities for prolonged periods of time. Figure 7 shows the changes in heart rate for two soccer players performing aerobic high-intensity training in a soccer drill called pendulum (Bangsbo 2005).

Table 1. Principles of aerobic training

Aerobic training	Heart rate			
	Mean		Range	
Low intensity	65*	130†	50–80*	100–160†
Moderate intensity	80*	160†	65–90*	130–180†
High intensity	90*	180†	80–100*	160–200†

*Measurement in $\%HR_{max}$ (maximal heart rate).
†Measurement in beats min^{-1}, if $HR_{max} = 200$ beats min^{-1}.

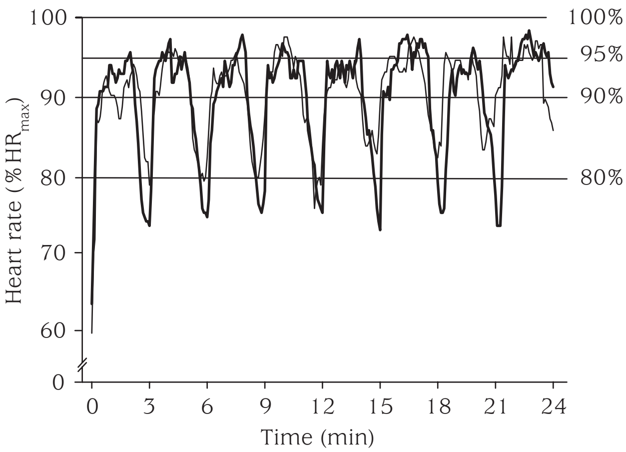

Fig. 7 Heart rate in percentage of individual maximal heart rate (HR_{max}) for two players during an aerobic high-intensity exercise drill called "Pendulum". The maximal heart rates of the players were 185 and 206 beats min^{-1}.

Anaerobic training

In a number of sports an athlete performs activities that require rapid development of force such as sprinting, quickly changing direction or jumping, which are associated with a high rate of creatine phosphate (CP) utilization. Also in many sports, the lactate-producing energy system (glycolysis) is highly stimulated during periods of competition. Therefore, the capacity to perform high-intensity exercise, and in many sports repeated intense exercise, may specifically have to be trained. This can be achieved through anaerobic training.

Anaerobic training results in an increase in the activity of creatine kinase and glycolytic enzymes. Such an increase implies that a certain change in an activator results in a higher rate of energy production of the anaerobic pathways. Intense training does not appear to influence the total creatine phosphate pool, but it allows the muscle glycogen concentration to be elevated, which is of importance for performance during repeated high-intensity exercise (Reilly & Bangsbo 1998). The capacity of the muscles to release and neutralize H^+ (buffer capacity) is also increased after a period of anaerobic training (Juel et al. 2004; Pilegaard et al. 1999). This will lead to a lower reduction in pH for a similar amount of lactate produced during high-intensity exercise. Therefore, the inhibitory effects of H^+ within the muscle cell are smaller, which may be one of the reasons for a better performance in high-intensity tests after a period of anaerobic training. Another important effect of anaerobic training is an increased activity of the muscle Na^+/K^+ pumps resulting in a reduced net loss of potassium from the contracting muscles during exercise, which may also lead to increased performance (Nielsen et al. 2004).

The overall aim of anaerobic training is to increase an athlete's potential to perform high-intensity exercise. The specific aims of anaerobic training are summarized as follows.

- To improve the ability to act quickly and to produce power rapidly. Thus, an athlete reduces the time required to react and elevates the performance of sprinting.
- To improve the capacity to produce power and energy continuously via the anaerobic energy-producing pathways. Thereby, an athlete elevates the ability to perform high-intensity exercise for a longer period of time.
- To improve the ability to recover after a period of high-intensity exercise, which is particularly important in ball games. As a result, an athlete requires less time before being able to perform maximally in a subsequent period of exercise, and in ball games the athlete will, therefore, be able to perform high-intensity exercise more frequently during a match.

Components of anaerobic training

Anaerobic training can be divided into speed training and speed endurance training (Figure 6). The aim of speed training is to improve an athlete's ability to act quickly in situations where speed is essential. Speed endurance training can be separated into two categories: production training and maintenance training. The purpose of production training is to improve the ability to perform maximally for a relatively shorter period of time, whereas the aim of maintenance training is to increase the ability to sustain exercise at a high intensity. Table 2 shows the principles of the various categories of anaerobic training.

Anaerobic training must be performed based on an interval principle. During speed training, the athletes should perform maximally for a shorter period of time (<10 s). The periods between the exercise bouts should be long enough for the muscles to recover to near-resting conditions, to enable an athlete to perform maximally in a subsequent exercise bout. In many sports, speed is not

Table 2. Principles of anaerobic training

Anaerobic training	Exercise(s)	Rest(s)	Intensity*	Repetitions
Speed	2–5	>50	Maximal	5–20
	5–10	>100	Maximal	2–10
Speed endurance production	20–90	>5 times exercise duration	Very high	2–10
Speed endurance maintenance	20–90	<3 times exercise duration	High–very high	2–10

*Maximal, very high and high intensity corresponds to 100%, 70–100% and 45–70% of maximal intensity, respectively.

merely dependent on physical factors. It also involves rapid decision making, which must then be translated into quick movements. Therefore, in ball games speed training should mainly be performed with a ball. Speed drills can be designed to promote an athlete's ability to sense and predict situations, and the ability to decide on the opponents' responses in advance.

By speed endurance training the creatine kinase and glycolytic pathways are highly stimulated. The exercise intensity should be almost maximal to elicit major adaptations in the enzymes associated with anaerobic metabolism. In production training the duration of the exercise bouts should be relatively short (20–40 s), and the rest periods in between the exercise bouts should be comparatively long (2–4 min) in order to maintain a very high intensity during the exercise periods throughout an interval training session. In maintenance training the exercise periods should be 30–90 s and the duration of the rest periods should be one- to three-fold longer than the exercise periods, to allow athletes to become progressively fatigued. The adaptations caused by speed endurance training are mostly localized to the exercising muscles. Thus, it is important that an athlete performs movements in a manner similar to during competition, e.g., an oarsman should train in the boat or on a rowing ergometer. In ball games this can be obtained by performing high-intensity games or drills with a ball.

Specific muscle training

Specific muscle training involved training of muscles in isolated movements. The aim of this type of training is to increase the performance of a muscle to a higher level than can be attained just by participating in the sport. Specific muscle training can be divided into muscle strength, muscle speed endurance, and flexibility training (Figure 6). The effect of this form of training is specific to the muscle groups that are engaged, and the adaptation within the muscle is limited to the kind of training performed. A brief description of muscle strength training is given below. Further information about strength training as well as an overview of muscle endurance and flexibility training can be obtained elsewhere (Blomfield & Wilson 1998; Bangsbo 1994).

Strength training

In many sports there are activities that are forceful and explosive, e.g., high-jumping, hiding in boxing, and turning in ice hockey. The power output during such activities is related to the strength of the muscles involved in the movements. Thus, it is beneficial for an athlete in such sports to have a high level of muscular strength, which can be obtained by strength training.

Strength training can result in hypertrophy of the muscle, partly through an enlargement of muscle fibers. In addition, training with high resistance can change the fiber-type distribution in the direction of fast twitch fibers (Aagaard & Bangsbo 2005; Andersen et al. 1994). There is also a neuromotor effect of strength training and a part of the increase in muscle strength can be attributed to changes in the nervous system. Improvements in muscular strength during isolated movements seem closely related to training speeds. However, significant increase in force development at very high speeds (10–18 rad s^{-1}) have also been observed with slow-speed high-resistance training (Aagaard et al. 1994).

One essential function of the muscles is to protect and stabilise joints of the skeletal system. Hence, strength training is of importance also in preventing injuries as well as re-occurrence of injuries. A prolonged period of inactivity, e.g., during recovery from an injury, will considerably weaken the muscle. Thus, before an athlete returns to training after an injury, a period of strength training is needed. The length of time required to regain strength depends on the duration of the inactivity period but generally several months are needed. For a group of soccer players observed 2 years after a knee operation, it was found that the average strength of the quadriceps muscle of the injured leg was only 75% of the strength in the other leg (Ekstrand 1982).

The overall aim of muscle strength training is to develop an athlete's muscular make-up. The specific aims of muscle strength training are:

- To increase muscle power output during explosive activities such as jumping and accelerating
- To prevent injuries
- To regain strength after an injury

Components of strength training

Strength training can be divided into functional strength training and basic strength training (Figure 6). In functional strength training, movements related to the sport are used. The training can consist of activities in which typical movements are performed under conditions that are physically more stressful than normal. During basic strength training muscle groups are trained in isolated movements. For this training different types of conventional strength training machines and free weights can be used, but the body weight may also be used as resistance. Strength training should be carried out in a manner that resembles activities and movements specific to the sport. Based on the separate muscle actions the basic strength training can be divided into isometric, concentric and eccentric muscle strength training (Figure 6). Common to the different types of strength training is that the exercise should be performed with a maximum effort. After each repetition an athlete should rest a few seconds to allow for a higher force production in the

Table 3. Training schedule for two 9-day periods (phases 1 and 2) for the Danish National Soccer team before EURO 2004

Day	Phase 1		Phase 2	
	Morning	Afternoon	Morning	Afternoon
1	Yo-Yo IE2 test Technical/tactical training	Aerobic_{HI} training (6 × 2 min) Play—20 min	Yo-Yo IE2 test Technical/tactical training	Speed training Technical/tactical training Play—20 min
2	Free	Technical/tactical training	Free	Aerobic_{HI} training (6 × 2 min) Technical/tactical training Play—20 min
3	Technical/tactical training	Speed training Technical/tactical training Speed endurance maintenance training	Technical/tactical training	Speed training Technical/tactical training
4	Free	Technical/tactical training Play—30 min	Group C: Speed endurance Production training	Friendly game (evening)
5	Free	Speed training Aerobic_{HI} training (8 × 2 min) Play—20 min	Free (traveling)	Free (traveling)
6	Free	Technical/tactical training Group C: Aerobic_{HI} training (6 × 2 min)	Aerobic_{MI} (3 × 5 min) Play—30 min	Free
7	Free	Friendly game	Technical/tactical training	Speed training Technical/tactical training Speed endurance production training
8	Free	Group A: Recovery training Group B: Speed training Play—30 min	Free	Technical/tactical training
9	Free	Aerobic_{HI} training (8 × 2 min) Play—20 min	Yo-Yo IE2 test Technical/tactical training	Speed training Technical/tactical training Play—20 min

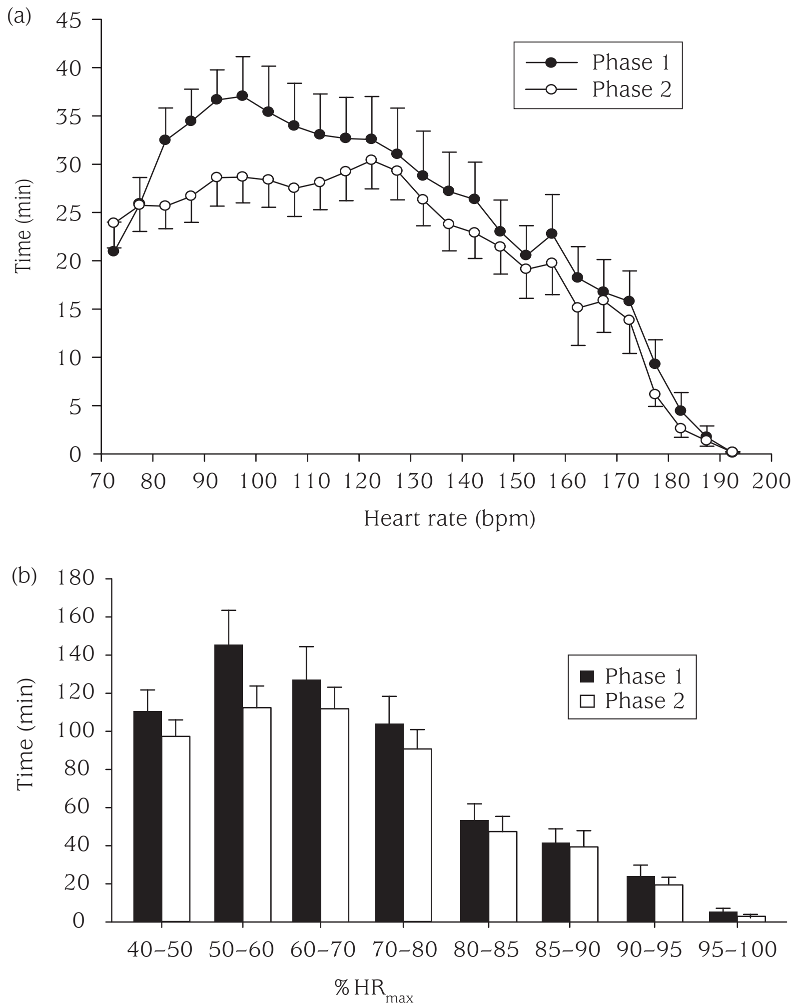

Fig. 8 Heart-rate distribution during two 9-day preparation periods (phases 1 and 2) for the Danish National team soccer squad before the European Championship 2004. The values are expressed as mean ± SEM in: (a) beats min^{-1}; and (b) % HR_{max}.

subsequent muscle contraction. The number of repetitions in a set should not exceed 15. During each training session two to four sets should be performed with each muscle group, and rest periods between sets should be longer than 4 min. During this time the athletes can exercise with other muscle groups. Several principles can be used in strength training (Ritzdorf 1998).

Planning fitness training

The time course of adaptations in the various tissues should be taken into account when planning fitness training. A change in heart size is rather slow, and there is a need for training over a longer period of time (years) to improve the pump capacity of the heart significantly (Blomqvist & Saltin 1983). Blood volume changes more quickly than the heart size, but this adaptation is optimal first after a dimensional development of the cardiovascular system has occurred. The content of oxidative enzymes in a tissue and the degree of capillarization of skeletal muscle change more rapidly than the volume of a tissue, e.g., the heart, but months of regular training are needed to obtain considerable increase in muscle capillaries and oxidative enzymes. On the other hand, a reduction in these parameters can occur with a time constant of weeks. The changes in glycolytic enzymes are rapid and they can be markedly elevated within a month of appropriate training (Reilly & Bangsbo 1998).

To give an example of the priorities and the amount of training within the different aspects of training in a top sport, the program of the preparation of the Danish National soccer team for the European Championship 2004 will be described. After the season the players had 1–2 weeks of holiday before they started preparing for the Championship. The preparation period lasted 18 days, which can be divided into two periods: 23rd May to 1st June (phase I) and 2nd June to 11th June (phase II). In each period the team played one match. The various elements of each training session are described in Table 3. The players were wearing heart-rate monitors during every training session allowing for an evaluation of the loading of each player during both phases of preparation. It should, however, be emphasized that the heart-rate measurements do not give a clear picture of the amount of anaerobic work performed during a training session. Figure 8 shows the distribution of the time in the different heart zones for the whole team. It is clear that the amount of work leading to a high heart rate was the same in the two phases, and that the total amount of training was reduced in the second phase. This is in accordance with more studies showing that performance can be maintained and improved by reducing the amount of low-intensity training and keeping a sufficient amount of high-intensity training (Mujika 1998; Shepley et al. 1992). It should be mentioned that the team seemed to have been well prepared, since they were able to qualify to the quarterfinals at the expense of Italy and Bulgaria.

The players were tested by the Yo-Yo intermittent endurance test (level 2) twice during the season as well as before and after phase I of the preparation period. It was clear that performance, measured as the

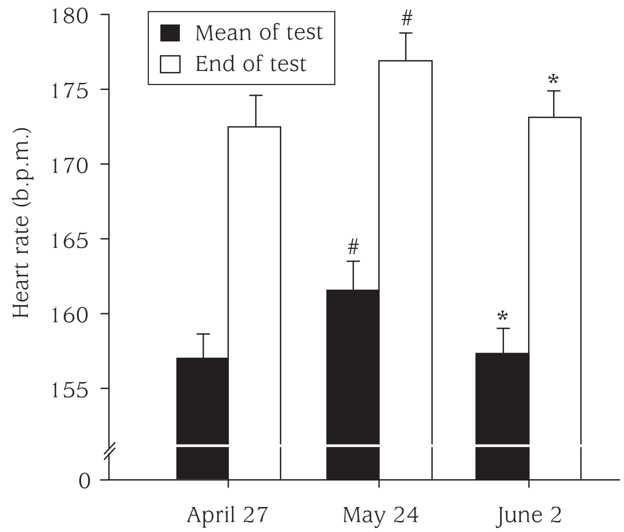

Fig. 9 Mean and end heart rate values of 18 players of the Danish National team soccer squad during a sub-maximal Yo-Yo intermittent endurance level 2-test performed 46, 19, and 10 days prior to the start of the European Championship 2004. The # symbol denotes a significantly higher heart rate during the test performed at May 24 compared to April 27. The * symbol denotes a significantly lower heart rate during the test performed at June 2 compared to May 24.

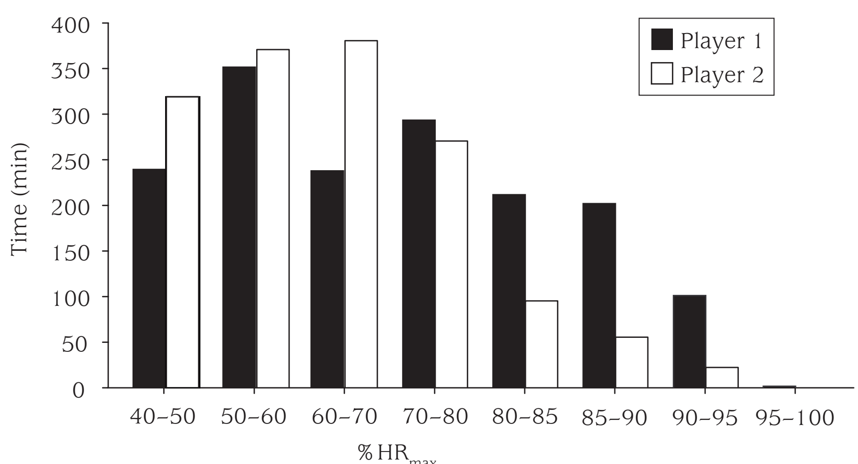

Fig. 10 Heart rate distribution of two players in the Danish National team soccer squad during an 18-day training period (sum of phases 1 and 2) before the European Championship 2004.

heart-rate response, was lower when they started the preparation period which by training during the first 10 days had reached the level of the season (Figure 9). This allowed the coaches to reduce the total amount of training in phase II of the preparation.

It should be emphasized that there were large individual differences in time where the players were in the high heart-rate zones (Figure 10). These variations were due to individual programs and large differences between players in the amount of high-intensity work performed during the tactical training. Therefore, it is essential to carefully evaluate the physical loading of the players also during training that are not having the specific aim of being in fitness training.

Conclusion

With appropriate training, performance of an athlete can be increased and the risk of injury can be reduced. To design an efficient training program it is important to be aware of the physical demands of the sport, the capacity of the athlete which can be determined by various tests, and the different components of fitness training. Aerobic training increases the ability to exercise at an overall higher intensity during competition, and minimizes a decrease in technical performance induced by fatigue. Anaerobic training elevates an athlete's potential to perform high-intensity exercise. Muscle strength training, combined with technical training, improves an athlete's power output during explosive activities in a match. Planning of fitness training is essential in top-class sport, and an example of the preparation of the Danish National Soccer team for the European Championship 2004 combined with physiological measurements and testing is provided taken into account individual needs.

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Role of muscle mass on sprint performance

Jorge Perez-Gomez [1], German Vicente Rodriguez [1], Ignacio Ara [1], Hugo Olmedillas [1], Safira Delgado-Guerra [1], Javier Chavarren [1], Juan Jose González-Enriquez [2], Cecilia Dorado [1], José A L Calbet [1].

[1] Department of Physical Education and Department of Mathematics [2], University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Canary Island, Spain.

Running head: muscle mass and sprint performance.

Address Correspondence to: J.A.L. Calbet

Departamento de Educación Física

Campus Universitario de Tafira

35017 Las Palmas de Gran Canaria

Canary Islands

Spain

Fax: 34-928-458867

e-mail: lopezcalbet@terra.es

Abstract

Purpose: To determine if gender differences in muscle mass explain the gender differences in running and cycling sprint performance.

Subjects and methods: Hundred and twenty-three men (age: 23.6±2.8 years, height: 176.1±6.3 cm, body mass: 74.1±8.6 kg; mean±SD), and thirty-two women (23.3±2.6 years, 165.1±6.4 cm, 60.3±5.7 kg) performed a 30 and a 300-m running test, and a Wingate test. Body composition was assessed by dual-energy X-ray absorptiometry.

Results: Peak power (PP) output in the Wingate test expressed per Kg of lower extremities lean mass (LM) was similar in males and females (50.4 ± 5.6 and 50.5 ± 6.2 $W.kg^{-1}$, P=0.88). No gender differences were observed in the slope of the linear relation between LM and (PP) or mean power output (MP). However, when MP was expressed per Kg of LM the males attained a 22% higher value (26.6 ± 3.4 and 21.9 ± 3.2 $W.kg^{-1}$, $P<0.001$). The 30 and 300-m running time divided by the relative lean mass of the lower extremities (RLM=LM*100/body mass) was significantly lower in males than in females (168.8 ± 16.9 and 233.7 ± 25.1 ms. % of muscle $mass^{-1}$, $P<0.001$) and (1776.9 ± 198.8 and 2719.5 ± 358.7 ms. % of muscle $mass^{-1}$, $P<0.001$). Although the slope of linear relation between RLM and 300-m running time was not significantly different between genders, the males achieved better performance in the 300-m test than the females.

Conclusions: The main factor accounting for gender differences in peak and mean power output during cycling is the muscle mass of the lower extremities. However, muscle mass only explains partially the gender difference in running sprints, even when expressed as a percentage of the whole body mass.

Key words: anaerobic capacity, cycle ergometry, short sprint, gender, exercise

Introduction

Sprint performance depends on the capacity to generate power and to achieve a high ratio between body mass and power (18, 19, 43, 55, 62). Moreover, Weyand et al. (62) showed that the main biomechanical variable determining differences in sprint running performance is the mean force applied during the ground contact phase of each step divided by the weight of the whole body. Chelly et al. (19) reported in eleven handball players that acceleration was significantly correlated with forward power only when expressed per unit of body mass ($W \cdot kg^{-1}$: specific power), whereas the maximal running velocity was only correlated with the total forward power of the body (W: absolute power). These authors reported that the leg muscle volume (estimated by anthropometry) was correlated with maximal running velocity in eleven teenage handball players (19). However, they did not perform a direct assessment of muscle mass. Since muscle mass is a major determinant of maximal force (24, 38, 56), and power results from the product of force and velocity, we hypothesise that sprint running performance depends among other factors on the muscle mass of the lower extremities in male and females adjusted for the whole mass (body weight) of the sprinter.

There are two major differences between sprint running and sprint tests on a static cycle ergometer. First, during sprint running work has to be done to transport the own body mass, this fact may be taken into account by just adjusting the power developed during static cycling by the body mass. Second, during running the stance phase may be decomposed into a eccentric and a concentric phase (37). Cavagna et al suggested that a sprint runner uses the work absorbed in his leg muscles (negative work, eccentric phase) at high speed to release further positive work (concentric phase) and thus increase power output (16). Thus, muscle mass may play different roles during sprint cycling and sprint running, and this effect may show gender dymorphism, due to the greater capacity of females to store and utilise elastic energy during the stretch-shortening cycle (31).

Therefore the main aims of this study were: 1) to determine if the muscle mass of the lower extremities influences sprint performance in events with high and low recruitment of the stretch-shortening cycle, such as running and cycling; 2) to determine if muscle mass has a different impact on sprint performance in males and females; and 3) to assess if sprint cycling performance has a similar predictive value for sprint running performance in males and females.

Methods

Subjects.

Hundred and twenty-three men physical education students (age 23.6 ± 2.8 years, height 176.1 ± 6.3 cm, body mass 74.1 ± 8.6 kg; mean ± SD), and thirty-two women physical education students (age 23.3 ± 2.6 years, height 165.1 ± 6.4 cm, body mass 60.3 ± 5.7 kg; mean ± SD) participated in the study. The study was performed in accordance with the Helsinki Declaration of 1975 as regards the conduct of clinical research, being approved by the Ethical Committee of the University of Las Palmas de Gran Canaria. Subjects provided their written consent before participation in the study.

General overview

All subjects were explored with a dual X-ray absorptiometer to determine their body composition and performed a 30 and a 300-m running test and a Wingate test. The running tests and the Wingate test were carried out in different days.

Lower limbs (LM) and total lean mass (TM)

Total lean mass and lean mass of the lower limbs (lower limb mass – [lower limb fat mass + lower limb bone mass]) was assessed by dual-energy X-ray absorptiometry (DXA) (QDR-1500, Hologic Corp., Software version 7.10, Waltham, MA) as reported in Calbet et al. (13) and Ara et al. (4). DXA equipment was calibrated using a lumbar spine phantom and following the Hologic guidelines. Subjects were scanned in supine position and the scans were performed in high resolution. Lower limb lean mass (kg) was calculated from the regional analysis of the whole body scan and it has been considered equivalent to the lower limb muscle mass. In addition, the relative lean mass of the lower extremities was calculated as [(lower extremities lean mass) x 100]/(whole body mass).

Running sprint tests

Subjects performed three maximal indoor short sprint trials, each separated by at least 5 minutes. The time required to cover 30-m was recorded with photoelectric cells (General ASDE, Valencia). The timer is automatically activated when the subject crossed the first cell, every 5-m thereafter. The subjects were encouraged to run as fast as they could. A standing start was used and the best of the three trials was selected as the representative value of this test (58). Another day, an all-out 300-m running test was carried out on a 400-m track; the time was recorded manually with a digital stopwatch.

All-out 30-s sprint test.

Stop start Wingate tests were performed on a modified mechanically braked ergometer (Monark 818E, Monark AB, Vargerg, Sweden) equipped with a SRM power meter (Schoberer, Germany) with a braking load equivalent to 10 and 8% of body mass for men and women, respectively (15). This test was preceded by at least 2 familiarisation Wingate tests in the precedent days. During the Wingate tests double-toe stirrups and straps were used to tightly fix the feet to the pedals. The subjects carried out a standardised warm-up consisting of 10 minutes of continuous cycling at intensity close to 80 watts followed by 5 maximal accelerations lasting 6-s every minute since minute 6. Then the participants rested 5 minutes and performed an all-out 30-s effort with verbal encouragement. The resistance assigned for each subject was 0.1 and 0.08 kp per kg of body mass in men and female respectively. Peak power output (PP) was calculated as the highest work output performed during 1 second interval, and mean power output (MP) as the average work performed during the 30 seconds.

Statistical analysis

Means and standard deviations (SD) are given as descriptive statistics. The relationship between variables was tested using linear regression. To test the similarity of slopes and intercepts of these relationships, the corresponding t test was applied for the model: $Y_{ij} = \alpha_i + \beta_i X_{ij} + \varepsilon_{ij}$ for $i = 1,2$ (1 = Men, 2 = Women) and $j = 1,\ldots, n_1$ being ε_{ij} i.i.d. random variables following a distribution $N(0, \sigma_1)$. Variables that correlated better with performance were included in a linear stepwise multiple regression analysis to determine which variables are more relevant to predict performance. Some of the comparisons between genders were carried out using ANOVA with gender as a factor with two levels. SPSS package (SPSS Inc, Chicago, IL) for personal computer was used for the statistical analysis. Statistical significance was set at $P < 0.05$.

Results

In men, the absolute lean mass of the lower extremities was linearly related to the peak and mean Wingate test power output ($r = 0.66$-0.73, $p < 0.01$). In women, the absolute lean mass of the lower extremities was linearly related to the 300-m running time, peak and mean Wingate test power output ($r = -0.53$, 0.66, 0.77, respectively, all $p < 0.01$) (Figure 1).

The relative lower extremities lean mass was linearly related to the 30-m and 300-m running time, and to the peak and mean power output in men ($r = -0.42$, -0.38, 0.21, 0.23, respectively, all $p < 0.01$ and to the 300-m running time in women ($r = -0.51$, $p < 0.01$) (Figure 2).

No significant differences between genders were observed in the slope of the linear relationship between the lean mass of the lower extremities and the peak or mean power output achieved in the Wingate test. Although the intercept of the linear relationship between lean body mass and mean power output was significantly lower in females than males. This indicates that the contribution of muscle mass to peak and mean power output is essentially similar in both genders. In addition, when peak power output in the Wingate test was expressed per Kg of lower extremities lean mass the results were also similar (50.4 ± 5.6 and 50.5 ± 6.2 W.kg of muscle mas^{-1}, in males and females, respectively, P=0.88). However, when mean power output in the Wingate test was expressed per Kg of lower extremities lean mass the males attained a 22% higher value than the females (26.6 ± 3.4 and 21.9 ± 3.2 W.kg of muscle mass^{-1}, in males and females, respectively, P<0.001).

The 30-m running time divided by the relative lean mass of the lower extremities was significantly lower in males than in females (168.8 ± 16.9 and 233.7 ± 25.1 ms. % of muscle mass^{-1}, males and females, respectively P<0.001). The slope of linear relation between the relative muscle mass of the lower extremities and 300-m running time was not significantly different between genders. However the intercept was higher for the females. For a given percentage of relative muscle mass the males achieved better performance in the 300-m test than the females (1776.9 ± 198.8 and 2719.5 ± 358.7 ms. % of muscle mass^{-1}, males and females, respectively P<0.001).

Bivariate correlations

A correlation matrix between running sprint performance and laboratory measured variables is shown in Table 2. When males and females were pooled together into single group the strongest relationship between the results in the Wingate test and body composition was found between mean power output and whole body and lower extremities lean masses (r = 0.90, p < 0.01; Table 2).

The 30-m time in men was significantly correlated with PP (r = - 0.36) and MP (r = - 0.34), while in women the correlation was observed only with PP (r = - 0.66) (table 2). However, normalising power output in the Wingate test to whole body mass (W.Kg^{-1}) improved these correlations to r = -0.55 in males, and r = - 0.73 in females (both p<0.05). Normalising PP by lower extremities lean mass produced slightly lower correlation coefficients (r = -0.39 and r = -0.70, in males and females, respectively, both p<0.05). Likewise, normalising the mean power output for whole body mass gave to better correlation between MP and 30-m running time (r = -0.58 and r = -0.40, in males and females, respectively, both p<0.05).

The 300-m running time was significantly correlated with PP (r = - 0.25 and r = - 0.53, in males and females, respectively, both p<0.05). Normalising PP to whole body mass resulted in better correlations (r = -0.41 and r = -0.64, in males and females, respectively, both p<0.05). However the correlation between 300-m and PP were slightly lower when PP was normalised to the lean mass of the lower extremities (r = -0.24 and r = -0.30, in males and females, respectively, both p<0.05).

The correlation between 300-m running time and MP was r = - 0.27 and r = -0.44, in males and females, respectively (both p<0.05). Normalising by body mass MP resulted in better correlations (r = -0.46 and r = - 0.56, in males and females, respectively, both p<0.05).

Multiple regression analysis: 300-m as the dependent variable

Linear stepwise multiple regression analysis to predict 300-m running time performance in men, women, and men and women combined into a single group are depicted in Table 3. In men, this analysis showed that the percentage of body fat, mean power output in the Wingate test and age are significant predictor of 300-m running time, explaining each 19, 8 and 4% of the variability in running time. When 30-m sprint performance was added to the regression analysis, it was observed that this variable is the one having the highest predictive value for 300-m time in men, explaining 23% of variance in 300-m time, while the %BF, MP and age contributed each to explain 7, 4 and 3% of the variance in 300-m time, respectively.

In women, the main contributor to the variance in 300-m time was the peak power output achieved during the Wingate test which explained alone 32% of variance in running time, while the percentage of body fat explained 10% of the variance in running time. When the 30-m running time was considered in regression analysis, this variable alone explained 34% of the variance in 300-m time, while the whole body lean mass accounted for 14%. When men and women were combined into a single population, 300-m running time was better predicted by the mean power output in the Wingate test, which accounted for 53% of variance in 300-m time. The %BF and age explained 17 and 1%, respectively of the variance in 300-m running time. Considering into the regression analysis the 30-m running time showed that this variable alone was able to explain 66% of the variance in 300-m time, while the whole body lean mass, %BF and age accounted for 8, 3 and 1% of the variance in 300-m running time. The peak power output achieved during the Wingate test, the whole body lean mass and the lean mass of the lower extremities explained 11, 6, and 3% of the variance in 30-m running time.

Multiple regression analysis: 30-m as the dependent variable

Linear stepwise multiple regression analysis to predict 30-m running time performance in men, women and mean and women combined into a single group are depicted in Table 4. In men, 30-m running time was best predicted by the percentage of body fat which accounted by itself for 13% of the variance in 30-m time. The peak power achieved during the Wingate test, the whole body lean mass and the lower extremities lean mass accounted for 11, 6 and 3% of the variance en 30-m running time.

In women, the peak power achieved during the Wingate test was the best predictor of the 30-m running time, explaining alone 42% of the variance in 30-m running time, while whole body lean mass accounted for 9% of the variance in 30-m running time.

When mean and women were pooled together into a single population, the 30-m running time was best predicted by the mean power output in the Wingate test, which explained 52% of the variance in 30-m running time. Additional variable with predictive value for he 30-m running time were %BF, whole body lean mass and peak power output achieved in the Wingate test, which accounted for 9, 2, and 1% of the variance in 30-m running time.

Discussion

The main aim of this study was to determine if the muscle mass of the lower extremities influences sprint performance in events with high and low recruitment of the stretch-shortening cycle, such as running and cycling, and to assess if there are gender differences in the role played by muscle mass in sprint performance.

Gender differences in sprint performance have received limited attention (20). It is known that males have a higher absolute power than females and also have a higher relative power than females when power is expressed normalised to whole body mass (7, 29, 57). Our study clearly shows a linear association between absolute lean mass of the lower extremities and peak power output during the Wingate test. Moreover, this relationship is similar in men and women to the extend that in both groups the mean peak power output achieved during the Wingate was close to 50 w per Kg of lean mass in the lower extremities. In addition, the regression analysis shows that peak power output increases linearly in both genders with the amount of lean mass present in the lower extremities (slopes and intercepts of the linear relationships were similar). The fact that power output normalised to lower extremities muscle mass is the same in males and females strongly suggest that the main reason for the gender difference in peak power output during the Wingate test is that females have a lower muscle mass.

Skeletal muscle single fibre studies have shown that two main factors that determine fibre power: maximal shortening velocity and maximal specific tension (maximal isometric force divided by cross sectional area) (39). Maximal shortening velocity depends on several factors among which the most relevant are the predominant isoform of myosin heavy chain, with a smaller influence of light chain isoforms (12).

Maximal isometric force is mainly dependent on cross sectional area (54). In turn, the fiber's cross sectional area depends on many factors including genetic factors, hormones, growth factors, nutritional and mechanical factors (10, 50). No gender differences have been reported in fibre types in humans with different athletic status (3, 17, 48, 51, 52). In addition, among the many structural factors that could potentially explain gender differences in force generation capabilities such as, muscle cross sectional area, specific tension (force per cross sectional area), tendon stiffness, penneation angle, fibre length, fascicle length, marked differences have been reported only for muscle cross sectional area (1-3, 32, 35, 44, 52) and tendon stiffness (8), both being greater in males than females.

Sex differences in passive stiffness have been reported for the knee flexors (9, 25), knee joint complex (46), ankle joint complex (49), tendon structures (tendon and aponeurosis) in the medial gastrocnemius muscle (34) and elbow flexors (21). Similarly, sex differences in active tendon stiffness have been described for the knee flexors (9, 27) and the lower extremity (26).

However, the gender difference in tendon stiffness is not greater than the gender difference in muscle strength, and in each gender tendon stiffness is proportional to the strength of the muscles acting on it (6). Although some gender differences in fibre length, and angle of pennation have been reported (34) the muscle with greater force producing capabilities as a function of architecture would be expected to have a greater capacity to resist changes in musculotendinous length (i.e. display greater stiffness) when comparing two muscles of equal absolute size. Consequently, gender differences in tendon stiffness hardly could account for the gender differences in power performance, particularly during sprint cycling.

In theory the more complying tendons of females should allow for a greater storage and release of energy during stretch-shortening activities such as sprint running, as reported during jumping (31). However, our results did not allow to confirm or disprove this hypothesis. This study shows that while differences in absolute muscle mass could explain the totality of the gender differences in peak power output during sprint cycling, this is not the case during sprint running. The multiple regression analysis applied in the present investigation indicates that other factors could play a role, such as the percentage of body fat.

Weyand et al. (62) showed that faster top running speeds are achieved with greater ground forces not more rapid leg movements. It is likely that this also applies to the male-female comparison (33). Top males sprinters are about 7.3% faster than their female counterparts (20), likely because male sprinters are able to generate higher ground reaction forces and, hence, longer strides (33). How is this brought about remains a mystery.

This study also shows that differences in muscle mass account for part of the sex differences in mean power output during the Wingate test and 300-m running time. No significant gender differences were observed in the slope of the relationship between the lean mass of the lower extremities and mean power output in the Wingate test, indicating that mean peak power output increases with a greater muscle mass almost in the same magnitude in males and females. However, the fact that the intercept of this relationship was lower in females and that mean power output in the Wingate test was 22% higher in males suggest that other factors, in addition to muscle mass must contribute to explain the gender differences in performance during prolonged sprints. This finding is slightly different than that reported by Weber et al. (59). These authors, based on an allometric study on 10 men and 10 women, have reported that after accounting for anthropometrical differences, the lower limb anaerobic power output of men and women is qualitatively similar (59). The discrepancy between our study and that of Weber et al. may rely on the fact that Weber et al. lacked of sufficient statistical power to appropriately compare between genders the slopes and intercepts of the relationship between muscle mass and power output, actually this kind of analysis is not presented by Weber et al.

The capacity to synthesise the ATP needed to sustain muscle contraction during a prolonged sprint is higher in males than females, likely due to the greater aerobic and anaerobic power of the former. Males have a greater anaerobic capacity than females, particularly due to their higher glycolytic capacity (28, 30, 32, 53). Type II fibres have higher glycolytic capacity than type I fibres (23), and although there are no sex differences in fibre type distribution, the area occupied by type II fibres is higher in men than women (30). However, when the activities of LDH and PFK are adjusted by gender differences in cross sectional area the gender differences in LDH and PFK activities disappeared (30). The latter agrees with the findings obtained in the present investigation showing that muscle mass accounts for a great part of the gender difference in mean power output during the Wingate test. Nevertheless, our results also indicate that factors other than differences in absolute and relative muscle mass should also play a role. In fact, it has been reported that men have also greater anaerobic capacity than women even when body size is taken into account (40, 60, 61).

During a sprint lasting for 30 seconds 20-30% of the ATP consumed is produced through the aerobic metabolism (14, 15, 42, 47), a figure that reaches a value close 50% of overall energy yield when the duration of the sprint is close to 60-s (42). VO_2max and the oxygen consumed during the Wingate test are highly correlated, meaning that subjects with higher VO_2max are able to provide a greater amount of ATP during the Wingate test through the oxidative metabolism (15). Males have a higher VO_2max (36) and peak muscle oxidative capacity than females (11, 28).

Predictive value of Wingate power output: absolute versus relative power

Our results indicate that that power output needs to be normalised to body mass for power output to improve its predictive value on sprint performance in either short (4-5 s) or long sprints (50-70 sec). This finding is in agreement with Baker and Nance (5, 22, 41). The studies having more heterogeneity in subjects performance such as that by Meckel et al. (41) who studied a group of 30 subjects with varied sprint ability (mean 100m time ranged from 11.1 seconds in the fastest group [n = 10] and 14.2 seconds in the slowest group [n = 10]) report the highest predictive value for sprint performance of power output normalised to body mass. In general, peak power output normalised to body mass has greater predictive value for running performance in short sprints than the absolute peak power output. Using the lean mass of the lower extremities as normalising variable does not improves the predictive value of peak power output beyond that obtained when the whole body mass is used as the normalising variable.

In agreement with our results mean power output (W/Kg) in the Wingate test has been reported to be correlated (r=-0.88) with the running time in 100m sprint (41) in females. Likewise, in males, the mean power output developed during a 10-s sprint on the cycle ergometer has also been reported to correlate with running time in a 40-m sprint (-0.46) (45). However, our study clearly shows that the peak power output is a more accurate predictor for short sprint performance than mean power output attained during the Wingate test. In addition, our data also indicate that the peak power output achieved during the Wingate test has also predictive value for sprint performance in 300m running test.

In summary, this study shows that the main factor accounting for gender differences in peak power output during cycling is the muscle mass of the lower extremities. However, gender differences in prolonged sprint performance can be explained only partially by the sex differences in muscle mass and body fat, meaning that other factors, likely related with the capacity to sustain a high rate of ATP resynthesis should account for the sexual dymorphism in prolonged sprint performance. Although, the lower gender difference in short sprint performance during cycling compared to running may be caused by the higher body fat mass of women, more studies are required to identify the mechanisms implicated. The predictive value of the power output achieved during a Wingate test for running sprint performance is higher when the power is expressed relative to body mass rather than in absolute values.

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Table1. Subject's physical characteristics and test results.

Variables (Mean ± SD)	**Men**	**Women**
Age (years)	23.7 ± 2.8	23.3 ± 2.6
Body mass (Kg)	74.1 ± 8.6	60.3 ± 5.7 *
Height (cm)	176.1 ± 6.3	165.1 ± 6.4 *
Percentage of body fat (%)	15.4 ± 5.3	26.6 ± 6.2 *
Lower limb muscle mass (Kg)	19.5 ± 2.2	12.9 ± 1.2 *
Lean total muscle mass (Kg)	58.5 ± 5.7	41.0 ± 3.3 *
Peak power (W)	981.2 ± 145.0	652.8 ± 109.7 *
Mean power (W)	701.0 ± 85.4	465.0 ± 58.2 *
30-m time (s)	4.4 ± 0.2	5.0 ± 0.2 *
300-m time (s)	46.5 ± 3.0	57.8 ± 3.8 *

* $P < 0.05$ men vs. women

Table 2. Bivariate relationships between Wingate test performance, body composition and running sprint performance. Peak Power (PP), Mean Power (MP), Body mass (BM), Percentage of Body Fat (%BF), lower limb lean Mass (LM), total lean mass (TM), time to cover 30-m (30-m) and 300-m (300-m) running tests. * P < 0.05.

Men	300-m	30-m	%BF	LM	LT
PP	-0.25 *	-0.36 *	-0.02	0.66 *	0.67 *
MP	-0.27 *	-0.34 *	-0.01	0.73 *	0.74 *

Women	300-m	30-m	%BF	LM	LT
PP	-0.53 *	-0.66 *	0.03	0.66 *	0.57 *
MP	-0.44 *	-0.34	0.10	0.77 *	0.68 *

Men and women	300-m	30-m	%BF	LM	LT
PP	-0.70 *	-0.72 *	-0.45 *	0.84 *	0.84 *
MP	-0.74 *	-0.72 *	-0.49 *	0.90 *	0.90 *

Table 3. Linear stepwise multiple regression analysis to predict 300-m and 30-m running time performance in men, women and mean and women combined into a single group. Two different equations were calculated for each distance. For the first equation the variables included in the multiple regression analysis were: Peak power (PP), mean power (MP), lower extremities lean mass (LM) and total lean mass (TM), percentage of body fat (%BF) and age. In the second equation the variables included in the multiple regression analysis were: Peak power (PP), mean power (MP), lower extremities lean mass (LM) and total lean mass (TM), percentage of body fat (%BF) and age, and the time to cover 30-m (ms) (when the predicted variable was 300-m time).

300-m performance

Men		R	R^2
	%BF	0.45	0.19
	MP	0.53	0.27
	age	0.58	0.32
300-m time = 308.94 (age) -10.60 (MP) + 233.95 (%BF) + 43088.46			
	30	0.48	0.23
	%BF	0.56	0.30
	age	0.60	0.34
	MP	0.63	0.37
300-m time = -7.08 (MP) + 308.50 (age) + 160.21 (%BF) + 4583.71 (30) + 21475.87			

Women	R	R^2
PP	0.58	0.32
%BF	0.68	0.42
300-m time = 195.55 (%BF) – 18.47 (PP) + 64595.71		
30	0.60	0.34
TM	0.72	0.48
300-m time = -0.42 (TM) + 9311.70 (30) + 28394.59		

Men and women		R	R^2
	MP	0.73	0.53
	%BF	0.84	0.70
	Age	0.85	0.71
300-m time = 244.74 (age) + 345.46 (%BF) -23.28 (MP) + 52152.06			
	30	0.81	0.66
	TM	0.86	0.74
	%BF	0.88	0.77
	Age	0.89	0.78
300-m time = 223.31 (age) + 186.21 (%BF) - 0.20 (TM) + 8379.86 (30) +12967.24			

30-m performance

Men		**R**	**R^2**
	%BF	0.37	0.13
	PP	0.50	0.24
	LT	0.56	0.30
	MP	0.60	0.33

30-m time = - 1.08 (MP) + 0.02 (LT) - 0.36 (PP) + 13.54 (%BF) + 4387.53

Women		**R**	**R^2**
	PP	0.66	0.42
	LT	0.75	0.53

30-m time = 0.03 (LT) – 1.73 (PP) + 4977.34

Men and women		**R**	**R^2**
	MP	0.72	0.52
	%BF	0.79	0.61
	LT	0.80	0.63
	PP	0.81	0.64

30- m time = -0.57 (PP) + 0.01 (LT) + 16.97 (%BF) – 1. 22 (MP) + 4921.11

Figure legends

Fig. 1. Relationship between lower extremities limbs mass and 30-m, 300-m and Wingate performance.

Fig. 2. Relationship between the relative lean mass of the lower extremities (RLM = Lean mass * 100/body mass) and 30-m, 300-m and Wingate performance.

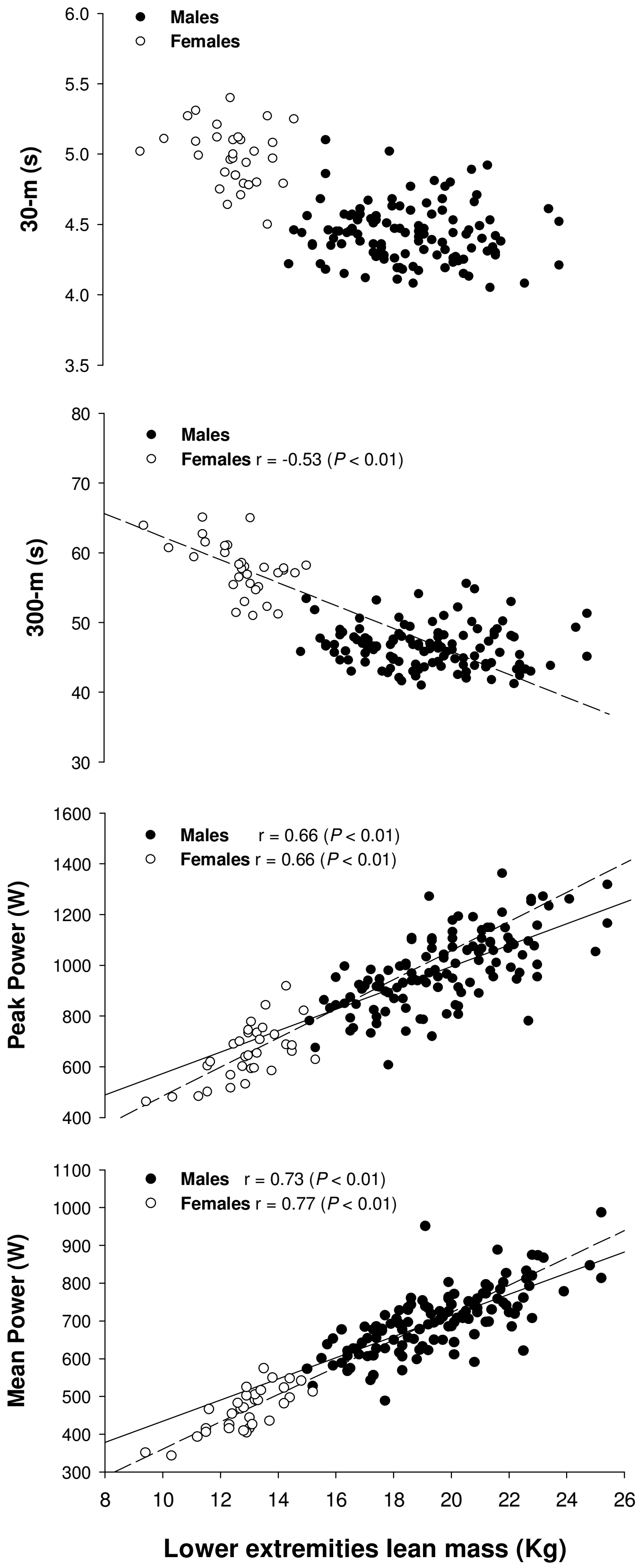
Males
Females
30-m (s)
6.0
5.5
5.0
4.5
4.0
3.5
Males
Females r = -0.53 (P < 0.01)
300-m (s)
80
70
60
50
40
30
Males r = 0.66 (P < 0.01)
Females r = 0.66 (P < 0.01)
Peak Power (W)
1600
1400
1200
1000
800
600
400
Males r = 0.73 (P < 0.01)
Females r = 0.77 (P < 0.01)
Mean Power (W)
1100
1000
900
800
700
600
500
400
300
8
10
12
14
16
18
20
22
24
26
Lower extremities lean mass (Kg)

Fig. 1

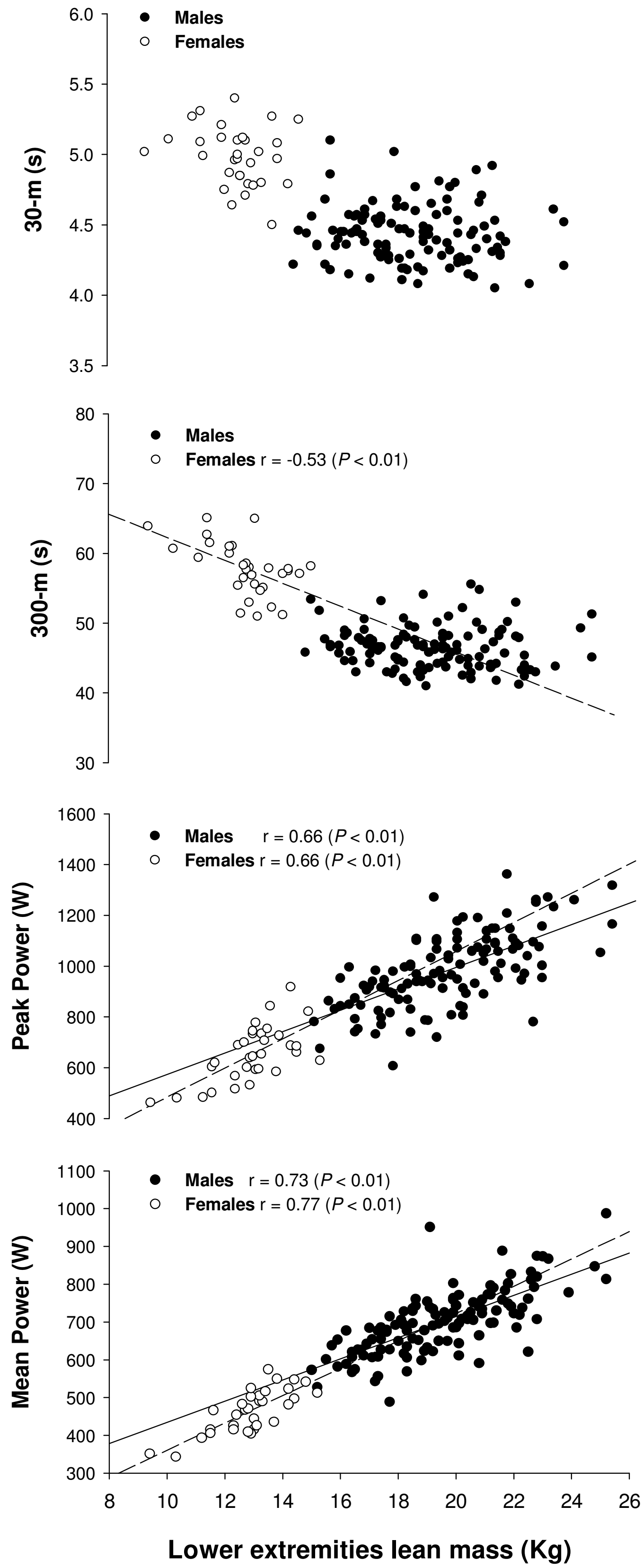
Males
Females
30-m (s)
Males
Females r = -0.53 (P < 0.01)
300-m (s)
Males r = 0.66 (P < 0.01)
Females r = 0.66 (P < 0.01)
Peak Power (W)
Males r = 0.73 (P < 0.01)
Females r = 0.77 (P < 0.01)
Mean Power (W)
Lower extremities lean mass (Kg)

Fig. 2

CAPACIDAD DE SALTO EN NIÑAS PREPÚBERES QUE PRACTICAN GIMNASIA RÍTMICA

Jorge Pérez-Gómez[1], Germán Vicente-Rodríguez[1], Ignacio Ara Royo[1], Rafael Arteaga[2], José A. L. Calbet[1], Cecilia Dorado[1].

[1]Departamento de Educación Física y [2]Departamento de Física. Universidad de Las Palmas de Gran Canaria, España.

RESUMEN

Estudiamos el rendimiento en el salto vertical y cómo podría verse afectado por la composición corporal en 13 niñas que practicaban gimnasia rítmica (GR; 10.4 ± 0.9 años) y 13 niñas control (CO; 9.9 ± 0.7 años). La composición corporal fue determinada mediante antropometría y DXA. Se realizaron saltos con y sin contramovimiento (CMJ y SJ) sobre una plataforma de fuerza analizándose entre otras variables la altura de vuelo (AV), velocidad de despegue (VD), velocidad vertical máxima del centro de masas (Vimax), la potencia media (Pm), el impulso mecánico positivo (Ipos), tiempo de fuerza máxima (Tfmax) y potencia instantánea máxima (Pimax). Las gimnastas consiguieron una AV, VD, Ipos y Vimax mayor en ambos saltos y una Pimax y Tfmax mayores en el CMJ que las control ($p<0.05$). En conclusión, practicar gimnasia rítmica 10 $h{\cdot}sem^{-1}$ se asocia a un mayor rendimiento en el salto vertical.

Palabras claves: gimnasia rítmica, entrenamiento de fuerza, capacidad de salto.

INTRODUCCIÓN

Son muy numerosos los estudios que han demostrado que con un programa de entrenamiento de fuerza se puede aumentar la capacidad de salto vertical tanto en adultos (Fatouros y col. 2000; Gehri y col. 1998; Newton y col. 1999) como en niños y niñas (Diallo y col. 2001; Hakkinen 1993; Matavulj y col. 2001). En los estudios realizados con niños, además del entrenamiento de fuerza, éstos participaban en alguna modalidad deportiva como el baloncesto (Hakkinen 1993; Matavulj y col. 2001) o el fútbol (Diallo y col. 2001). Este último hecho impide saber hasta qué punto la mejora de la capacidad de salto observada es debida al entrenamiento de fuerza o resulta del efecto combinado del entrenamiento de fuerza y la práctica deportiva habitual. La práctica de fútbol con una frecuencia de tres horas semanales sin participar en un programa específico de fuerza se asocia a una mayor capacidad de salto en el SJ en niños prepúberes (Vicente-Rodriguez y col. 2003). Sin embargo, en un estudio longitudinal de unos tres años de duración, los niños que practicaban al menos 3 horas semanales de actividad física extraescolar mejoraron su capacidad de salto con el crecimiento en la misma medida que los niños no deportistas (Vicente-Rodríguez y col. 2003). Así pues, no esta claro si se pueden alcanzar mejoras en el salto vertical sin someterse a un entrenamiento específico de fuerza. Por lo tanto, el objetivo del presente estudio fue determinar si las niñas prepúberes que practican un entrenamiento específico de gimnasia rítmica 10 horas semanales, sin estar sometidas a un programa de entrenamiento específico de fuerza, tienen mayor capacidad de salto vertical que las niñas que no practican deporte extraescolar de forma habitual.

METODOS

Veintiséis niñas prepúberes residentes en Gran Canaria (edad 10.1 ± 0.8 años, masa corporal 34.1 ± 5.1 Kg, talla 140.1 ± 5.8 cm y % de grasa corporal 24.9 ± 7.7, datos expresados en valores medios ± SD, Tanner ≤ 2), aceptaron de forma voluntaria y bajo consentimiento de sus padres participar en este estudio. Trece niñas que practicaban gimnasia rítmica diariamente con una frecuencia semanal de diez horas formaron parte del grupo experimental (GR), mientras que las otras 13 que no hacían actividad física de manera regular configuraron el grupo control (CO). El estado madurativo se determinó

mediante autoevaluación por el método Tanner (Tanner 1962) de contrastada validez (Duke y col. 1980) y alta fiabilidad (r = 0.97,(Morris y Udry 1980).
Para determinar las mejoras en el salto vertical se efectuaron tests de salto en una plataforma de fuerzas (Kistler, Winterthur, Switzerland) siguiendo el protocolo propuesto por Bosco y col. (1983). Durante la ejecución de los saltos, los niños mantuvieron las manos en la cintura para minimizar cualquier desplazamiento lateral y horizontal. Cada salto se realizó de forma explosiva intentando alcanzar la mayor altura posible. La técnica de salto vertical utilizada fue salto con contramovimiento (CMJ) y salto sin contramovimiento (SJ). En los CMJ el sujeto estaba en una posición erguida para luego flexionar rápidamente las rodillas hasta aproximadamente un ángulo de 90º y seguidamente efectuar la impulsión vertical hacia arriba. En los SJ el sujeto flexionaba las rodillas hasta alcanzar los 90º y desde esa posición saltaba hacia arriba sin contramovimiento. Todos los sujetos realizaron tres intentos para cada salto, siendo analizados todos ellos e incluido en los análisis posteriores el mejor de los tres. A partir de los datos proporcionados por la plataforma se midieron las siguientes variables: altura de vuelo (AV), velocidad de despegue (VD), fuerza máxima neta (Fmaxn = Fuerza máxima - peso corporal), tiempo necesario para alcanzar el valor máximo de fuerza (Tfmax), impulso mecánico positivo (Ipos) potencia instantánea media (Pm) y máxima (Pimax), la velocidad vertical máxima del centro de masas (Vimax) y el tiempo en alcanzar la velocidad vertical máxima del centro de masas (Tvimax). Los cálculos de potencia instantánea y la descomposición del salto CMJ en sus fases descendente y ascendente se realizó con software específicamente desarrollado en nuestro laboratorio.
Para determinar las medidas antropométricas se utilizó el protocolo “O-Scale System” (Ward y col. 1989). Posteriormente se determinó la composición corporal mediante absorciometría fotónica dual de rayos X (DXA) (QDR-1500, Hologic Corp., Software versión 7.10, Waltham, MA) tal como se ha descrito anteriormente (Calbet y col. 1998). Y Se obtuvieron datos de: masa magra total (LT), masa magra media de las extremidades superiores (MMB), masa magra media de las extremidades inferiores (MMP) y porcentaje de grasa corporal (%GC).

Análisis estadístico

Las variables se presentan como el valor medio ± error típico de la media (SEM). Las diferencias entre medias se establecieron mediante la prueba T de Student para datos independientes, tras comprobar que las variables analizadas se distribuían conforme a la curva normal mediante el test de Levene. Posteriormente se realizó la prueba ANCOVA con la masa corporal como covariable. Se han aceptado como significativas aquellas diferencias entre grupos con una probabilidad de ser debidas al azar igual o inferior al 5% ($p \leq 0.05$).

RESULTADOS

Las características generales así como los datos de composición corporal de los sujetos están resumidos en la tabla 1. Las niñas gimnastas presentan una masa corporal un 20% menor que las niñas control ($p < 0.05$) debido a un porcentaje de grasa corporal 8 puntos más bajo que el de las niñas control ($p < 0.05$) ya que la masa magra fue similar en ambos grupos.

Tabla 1. Composición corporal (media ± SEM) (GR = gimnasia rítmica; CO = niñas control).

Variables	GR	CO	Significación
Edad (años)	10.4 ± 0.9	9.9 ± 0.7	NS
Talla (cm)	138.8 ± 6.0	141.4 ± 5.4	NS
Masa corporal (Kg)	31.6 ± 3.4	36.5 ± 5.5	p<0.05
LT (Kg)	23.2 ± 2.9	23.9 ± 2.3	NS
MMB (Kg)	1.0 ± 0.1	1.0 ± 0.2	NS
MMP (Kg)	3.7 ± 0.7	3.8 ± 0.5	NS
% GC	21.0 ± 6.2	28.8 ± 7.3	p<0.01

Masa magra total (LT), masa magra media de las extremidades superiores (MMB), masa magra media de las extremidades inferiores (MMP), porcentaje de grasa corporal (%GC).

En la tabla 2 se muestran los resultados del test de salto vertical SJ y CMJ. Se realizó un análisis ANCOVA de las variables ajustando los valores respecto a la masa corporal. Los resultados demostraron que las niñas gimnastas obtuvieron una VD, AV, Ipos y Vimax un 12% ,25%, 10% y 9% superior en el SJ respectivamente, mientras que las ganancias fueron mayores un 15%, 34%, 11% y 12% respectivamente en el CMJ que las niñas control ($p < 0.05$). Además, durante el CMJ las niñas gimnastas desarrollaron una Pimax un 14% superior que las niñas control ($p < 0.05$). La potencia media por kg de masa corporal también fue superior en las gimnastas, tanto en los SJ como en los CMJs ($p<0.05$).

Tabla 2. Variables biomecánicas ajustadas para la masa corporal (media ± SEM) (GR = gimnasia rítmica; CO = niñas control).

Variables		GR	CO	Significación
SJ	**Vd (m/s)**	1.91 ± 0.05	1.70 ± 0.05	< 0.05
	Av (cm)	18.8 ± 0.01	15.0 ± 0.01	< 0.05
	Tfmax (s)	0.23 ± 0.02	0.18 ± 0.02	NS
	Fmaxn (Kp)	34.0 ± 1.7	36.8 ± 1.7	NS
	Ipos (Kp.s)	6.5 ± 0.2	5.9 ± 0.2	<0.05
	Pm (w)	464.3 ± 19.4	492.6 ± 27.0	NS
	Vimax (m/s)	2.00 ± 0.05	1.83 ± 0.05	< 0.05
	Tvimax (s)	0.32 ± 0.15	0.28 ± 0.15	NS
	Pimax (w)	1082.2 ± 36.1	989.1 ± 36.1	NS
	Tpimax (s)	0.28 ± 0.16	0.24 ± 0.16	NS
CMJ	**Vd (m/s)**	2.09 ± 0.05	1.81 ± 0.05	< 0.01
	Av (cm)	22.4 ± 0.01	16.7 ± 0.01	< 0.001
	Tfmax (s)	0.33 ± 0.02	0.41 ± 0.02	<0.05
	Fmaxn (Kp)	49.4 ± 3.6	44.6 ± 3.6	NS
	Ipos (Kp.s)	7.03 ± 0.16	6.31 ± 0.16	<0.01
	Pm (w)	719.7 ± 32.1	679.0 ± 37.4	NS
	Vimax (m/s)	2.17 ± 0.04	1.94 ± 0.04	<0.01
	Tvimax (s)	0.53 ± 0.03	0.61 ± 0.03	NS
	Pimax (w)	1225.4 ± 42.3	1072.9 ± 42.3	<0.05
	Tpimax (s)	0.49 ± 0.03	0.56 ± 0.03	NS

Velocidad de despegue (VD), altura de vuelo (AV), tiempo necesario para alcanzar el valor máximo de fuerza (Tfmax), fuerza máxima neta (Fmaxn), impulso mecánico positivo (Ipos), velocidad vertical máxima del centro de masas (Vimax), potencia instantánea media (Pm) y máxima (Pimax), y el tiempo en alcanzar la velocidad vertical máxima del centro de masas (Tvimax) y la potencia instantánea máxima (Tpimax)

En la tabla 3 se muestra la matriz de correlaciones entre las variables de composición corporal y las de salto vertical en ambos grupos conjuntamente. Siendo La Fmaxn, el Ipos, la Pm y la Pimax las que más intensamente correlacionaron con la masa magra total y regional en ambos saltos. También existe una correlación negativa entre la Av, Vd y la Vimax con el % GC en ambos saltos.

Tabla 3. Correlación entre algunas variables de salto vertical y variables de composición corporal, en las veintiséis niñas

Variables	**MMB**	**MMP**	**LT**	**%GC**
Av SJ	0.19	0.09	0.05	-0.45*
Vd SJ	0.22	0.11	0.08	-0.45*
Fmaxn SJ	0.52**	0.48*	0.49*	-0.11
Ipos SJ	0.43*	0.65**	0.70**	0.35

Pm SJ	0.36	0.52**	0.56**	0.21
Vimax SJ	0.23	0.16	0.12	-0.39
Pimax SJ	0.57**	0.72**	0.74**	0.15
Av CMJ	0.25	0.18	0.14	-0.46*
Vd CMJ	0.27	0.19	0.16	-0.47*
Fmaxn CMJ	0.56**	0.39*	0.41*	-0.33
Ipos CMJ	0.48*	0.73**	0.75**	0.31
Pm CMJ	0.61**	0.65**	0.66*	-0.78
Vimax CMJ	0.26	0.21	0.17	-0.42*
Pimax CMJ	0.64**	0.74**	0.74**	0.06
(*P < 0.05; **P < 0.01)				

Salto con y sin contramovimiento (CMJ y SJ), altura de vuelo (AV), velocidad de despegue (VD), fuerza máxima neta (Fmaxn), impulso mecánico positivo (Ipos), potencia instantánea media (Pm) y máxima (Pimax), velocidad vertical máxima del centro de masas (Vimax).

DISCUSIÓN

El objetivo del presente estudio fue determinar si la participación en una modalidad deportiva puede mejorar la altura de vuelo en el salto vertical en niñas prepúberes, cuando el entrenamiento no incluye ejercicios específicos para el desarrollo de la capacidad de salto vertical. Los resultados indican que la práctica de gimnasia rítmica con una frecuencia semanal de diez horas y sin entrenamiento específico de fuerza, se asocia a una mayor capacidad de salto vertical en niñas prepúberes.

Bencke y col. (Bencke y col. 2002) estudiaron a 185 niños y niñas que practicaban diferentes deportes, y observaron que los que realizaban gimnasia eran los mejores saltadores siendo su superioridad mayor al realizar DJ, ejercicio que implica una coordinación motora más compleja. También observaron que en los saltos que requerían menor dificultad motora como el SJ y CMJ estaban influenciados por el entrenamiento específico, pero en menor grado que el mostrado con el DJ. El SJ requiere sólamente de una acción concéntrica y por lo tanto puede ser considerado como el salto más simple para analizar la fuerza explosiva. Por otro lado, el CMJ requiere una activación excéntrica previa a una alta contracción concéntrica, lo cual implica una mayor complejidad en su ejecución, y el DJ supone una importante carga excéntrica seguida de una alta contracción concéntrica, por lo que probablemente es más complejo desde el punto de vista neuromotor. Esta podría ser la razón por la cual la diferencia entre las niñas de rítmica y las niñas del grupo control son más acusadas en el CMJ que en el SJ.

Debido a que el sistema neuromuscular se desarrolla desde el nacimiento hasta la edad adulta, parece ser que la participación en prácticas deportivas puede inducir a alteraciones específicas en el control neuromuscular de los músculos de las extremidades inferiores, dependiendo de la naturaleza e intensidad del entrenamiento. En esta línea, diversos estudios sugieren que el entrenamiento de fuerza en niños puede inducir cambios en la activación neural e incrementar la fuerza (Blimkie 1993; Ozmun y col. 1994). Además se sabe que la ejecución del salto vertical depende de la coordinación de las acciones segmentarias del cuerpo humano, las cuales están determinadas a través de la interacción entre la fuerza muscular, que esta modulada por impulsos del sistema nervioso central, y los momentos netos que tienen que ser generados alrededor de las articulaciones para lograr las demandas mecánicas que supone realizar un salto vertical (Rodacki y col. 2002). Por lo tanto, podría ser que la práctica de gimnasia rítmica mejore la coordinación en el salto vertical en niñas prepúberes.

Teniendo en cuenta que las ganancias de fuerza aumentan de una manera lineal con respecto a la edad, parece lógico pensar que en edades tempranas los niveles de fuerza alcanzados por los sujetos serán bajos y las diferencias observadas en los tests de salto puedan ser debidas a la propia coordinación o control neuromuscular. A este respecto, observamos que no existen diferencias significativas en cuanto a la fuerza máxima desarrollada durante el salto entre gimnastas y sedentarias.

Por otro lado, se ha observado que valores superiores de masa magra corporal total y menor porcentaje de grasa corporal se asocian a una mayor capacidad para generar impulso mecánico vertical lo que permite, en parte, una mayor capacidad de salto en jugadores profesionales de voleibol (23 años) (Ara Royo y col. 2003). Sin embargo, en deportistas más jóvenes (15-16 años) no se observó correlación entre la altura del salto alcanzada con un CMJ y la cantidad de masa magra total, así como el % de grasa (Ugarkovic y col. 2002). En esta línea, nosotros también hemos observado que a una edad tan temprana como los 10 años, en niñas que practican gimnasia rítmica no existe correlación entre la masa magra total y la altura de vuelo alcanzada tanto en el SJ como en el CMJ, mientras que el % de grasa parece mostrar una correlación negativa con el rendimiento en el salto vertical, tal y como hemos observado en varones prepúberes (Ara I y col. En prensa).

CONCLUSION

La práctica continuada de gimnasia rítmica en edades prepúberes se asocia a un mayor rendimiento en el salto vertical tanto en el SJ como en el CMJ. Nuestros resultados sugieren que la mayor capacidad de salto de las niñas que practican gimnasia rítmica, comparadas con las niñas que no practican deporte de forma regular no es debida a diferencias en la masa muscular. Otros factores relacionados con la composición fibrilar de la musculatura y con la coordinación del salto podrían explicar las diferencias observadas.

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Influence of jumping plyometric training on cycling sprint performance.

Jorge Pérez-Gómez, Germán Vicente-Rodríguez, Ignacio Ara Royo, Javier Chavarren Cabrero, José A López Calbet.

Departamento de Educación Física. Universidad de Las Palmas de Gran Canaria, España.

Correspondencia: José A López Calbet

Departamento de Educación Física

Campus Universitario de Tafira

35017 Las Palmas de Gran Canaria

Tel: 928458896

e-mail: : lopezcalbet@terra.es

RESUMEN

El entrenamiento de pliometría permite activar en mayor medida las unidades motoras rápidas y se ha mostrado eficaz para aumentar el rendimiento en esfuerzos que requieren la realización de ciclos estiramiento acortamiento. Sin embargo, se desconocen sus efectos sobre la potencia anaeróbica desarrollada en actividades cíclicas. Por este motivo se estudió el rendimiento en el test de Wingate de 18 estudiantes de educación física (23.0 ± 1.7 años) que fueron asignados aleatoriamente al grupo de pliometría (N = 11) o al grupo control (N = 7). De estos tests se obtuvieron resultados de potencia pico (PP), potencia media (MP), velocidad de pedaleo máxima (MPR) e índice de fatiga (FI), también se calculó el índice de fatiga relativo a la masa magra de las piernas (FIL) y el FI relativo a la masa corporal total (FIB). El grupo de pliometría incrementó la PP (4%, $p<0.05$), la MPR (4%, $p<0.05$), pero no la potencia media MP (3%, $p=0.09$), mientras que ninguna de las variables medidas cambió significativamente en el grupo control. En conclusión, 6 semanas de entrenamiento de pliometría permiten mejorar el pico de potencia y la velocidad de pedaleo máxima en el test de Wingate, y posiblemente la potencia media. Estos resultados demuestran que el entrenamiento pliométrico puede ser también útil para aumentar el rendimiento en esfuerzos explosivos cíclicos, casi exclusivamente concéntricos, como los esprints que realizan los ciclistas.

Palabras claves: Potencia anaeróbica máxima, entrenamiento de fuerza, cicloergómetro**,** ciclo estiramiento-acortamiento.

ABSTRACT

Plyometric training is though to specifically stimulate fast muscle fibres. It has been claimed that plyometric training it is appropriate to enhance performance in efforts involving stretch-shortening cycles, as for example the drop jumps. However, the effects of plyometric training on the anaerobic power developed during cyclic activities with almost pure concentric muscle contractions, similar to those performed by cyclists during a sprint, remains unknown. Wingate test performance was assessed in eighteen male physical education students (23.0 ± 1.7 years) who were randomly assigned to the plyometric group (11) and the control group (7). Peak power (PP), mean power (MP), maximal pedalling rate (MPR) and fatigue index (FI), were analysed. Fatigue index relative to lower limb lean mass (FIL) and total body mass (FIB) were also calculated. The plyometric group increased their PP (4%, $p<0.05$), MPR (4%, $p<0.05$), while MP showed a trend to a slightly higher value (3%, $p = 0.09$). In contrast, all variables remained unchanged in the control group. In conclusion, 6 weeks of plyometric training increase peak power and maximal pedalling rate and mean power output during the Wingate test. These results show that plyometric training may be useful to enhance performance in cyclic explosive efforts almost purely concentric, such as bicycle sprints.

Key words: Maximal anaerobic power, strength training, cycle ergometry, stretch-shortening cycle.

INTRODUCTION

Plyometric training is though to specifically stimulate fast muscle fibres (Enoka, 1996). It has been claimed that plyometric training it is appropriate to enhance performance in efforts involving fast stretch-shortening cycles and vertical jumps (Bobbert, 1990; Diallo et al, 2001; Matavulj et al, 2001). However, the effects of plyometric training on the anaerobic power developed during cyclic activities with almost pure concentric muscle contractions, similar to those performed by cyclists during a sprint, remains unknown.

Wingate test has been widely used to evaluate anaerobic power (Calbet et al, 2003; Dore et al, 2001; Hendriksen & Meeuwsen, 2003; Souissi et al, 2002) and in a less extent to evaluate the effects of different strength training methods (Bencke et al, 2002). The effect of plyometric training on sprint performance on the cycle ergometer has been studied by few researchers (Siegler et al, 2003; Witzke & Snow, 2000) with different results. Peak power output of the lower limbs during the Wingate test did not improve following 9-month of plyometric jump training (Witzke & Snow, 2000). In another study, 10 weeks in-season plyometric training and high-intensity anaerobic program was not enough to show differences in Wingate test comparing with a control group that completed only traditional aerobic soccer conditioning (Siegler et al, 2003). In contrast, Bencke et al (2002) observed differences in Wingate test performance in children from different sports. However, the observed differences disappeared after accounting for body mass differences (Bencke et al, 2002). Thus, it is possible that a requirement to improve sprint performance with plyometric training is the development of some degree of muscle hypertrophy. Therefore, the purpose of the present study was to determine the effects of short-term plyometric training on

Wingate test performance in physical education students, accounting for the changes observed in leg muscle mass.

METHODS

Eighteen male physical education students participated in this investigation (age 23.0 ± 1.7 years, mean ± SD, body mass: 73.2 ± 8.9 Kg). Subjects were randomly assigned to the plyometric group (N = 11) and the control group (N = 7). The plyometric group trained 3 days every week during 6 weeks, they performed drop jumps and standing jumps according to the program depicted in Table 1. The control group did not perform any kind of resistance training. The study was conducted as required by the Helsinki Declaration.

Wingate tests on a modified mechanically braked ergometer (Monark 818E, Monark AB, Vargerg Sweden) with a braking load equivalent to 10% of body mass were completed before and after the training period, as previously described (Calbet et al, 2003). One Wingate test was missing in the second assessment in one subject from the training group, this is reflected in Table 3. Peak power output (PP), mean power output (MP), maximal pedalling rate (MPR) and fatigue index (FI), were analysed. Fatigue index relative to lower limb lean mass (FIL) and total body mass (FIB) was also calculated.

Additionally, the lean mass of the lower extremities (lower extremities mass – [lower extremities fat mass + lower extremities bone mass]) was assessed by dual-energy X-ray absorptiometry (DXA) (QDR-1500, Hologic Corp., Software version 7.10, Waltham, MA). The DXA equipment was calibrated as recommended by the Hologic guidelines. Subjects were scanned in supine position and the scans were performed at high resolution. Lower extremities lean mass (Kg), which is equivalent to the muscle mass, was calculated from the regional analysis of the whole body scan. The assessment of lower extremities by DXA has a coefficient of variation close to 3% in our laboratory. Based on the results of previous studies, the plyometric program was directly supervised (Mazzetti et al, 2000). The second DXA assessment was missed by one subject in the control group, as reflected in Table 3.

Statistical analysis.

Mean and standard deviation (SD) are given as descriptive statistics. Differences between pre and post training within each group were established using Student's paired t-test. The differences between groups were analysed using Student's unpaired t-test. SPSS package (SPSS inc, Chicago, USA) was used for the statistical analysis. Significant differences were assumed when $p < 0.05$.

RESULTS

Body composition and physical characteristics.

The subject's body composition and physical characteristics before and after the training programme remained unchanged (Table 2). So, the training program did not induce the development of muscle hypertrophy.

Wingate test performance.

Table 3 summarises the results obtained during the Wingate tests. The plyometric group increased their peak power output (4%, $p<0.05$) and maximal pedalling rate (4%, $p<0.05$), while mean power output showed a trend to a slightly higher value after training (3%, $p=0.09$). In contrast, all variables remained unchanged in the control group. The fatigue index in absolute values or normalised either by body mass or lower limb lean mass was not influenced by training.

DISCUSSION

The primary aim of this study was to determine whether short-duration plyometric training with jumps has any effect on cycling sprint performance. Our results indicate that training during 6 weeks the extensor muscles of the lower extremities with plyometric exercises can effectively enhance the peak power and maximal pedalling rate, and a little less the mean power output performance during the Wingate test, in physical education students.

In agreement, it has been shown that plyometric training can increase performance in explosive movements such as countermovement jumps (Diallo et al, 2001; Matavulj et al, 2001) and squat jumps (Diallo et al, 2001). The latter study contrast with the results of other researchers (Siegler et al, 2003; Witzke & Snow, 2000). Siegler et al. (2003) studied thirty-four female (ages 16.5 ± 0.9 years) high school soccer players throughout a season. They did not find differences between pre and post-training in peak power and mean power in the Wingate test within or between experimental and control group, even after accounting for differences in body mass. During the study players continued with regular soccer practices and matches, and maybe this training during the season could have interfered on the results obtained in the Wingate tests. Witzke and Snow (2000) studied fifty-six girls (ages 14.6 ± 0.5 years) to investigate the effects of long-term (9 months) plyometric training. This study had limitations, i.e. it was not randomised and the control group was more physically active than the exercise group, even before the study. The fact that we studied active men, while the later studies analysed women could indicate also that men are more sensitive to plyometric training, as they are for example to strength training (Bamman et al, 2003).

The improvement in peak power and maximal pedalling rate with plyometric training observed in the present investigation could be explained by an enhancement in the percentage of type II muscle fibres, or a shift in the myosin heavy chain isoform expression from type I and type IIb to type IIa, favouring the development of stronger and faster muscle contractions after the plyometric training program. In fact, Dawson et al (1998) found that 6 weeks of sprint training (6 x 40 m, 24 s recovery between each; 3 sessions per week) can improve running sprint performance by 2-3% in subjects with a background training similar to that of our subjects. Like us, Dawson et al (1998) also observed increased performance in prolonged sprints, i.e. a finding comparable to the increase in mean power performance here reported. In the case of Dawson et al (1998) the enhancement of prolonged sprint performance was associated to an elevation of glycogen phosphorylase activity. May be a similar mechanism could explain the elevation of mean power output during the Wingate test with plyometric training.

Explosive movements generate selective recruitment of high threshold motor units (Behm & Sale, 1993), which respond to overloaded with a fast hypertrophy (Goldspink, 1991). It is likely that our plyometric training elicited some hypertrophy of type II fibres, which could have been below the detection power of our DXA scanner. Even without a concomitant shift in the myosin heavy chain isoform expression, an enhancement of the cross-sectional area occupied by the type II could explain our results. Our findings also agree with the recent report of higher peak power and velocity following squat jump training with light loads (Mc Bride et al, 2002). However, the advantage of plyometric training likely relies on its ability to promote more effectively an improvement in peak power. In fact, explosive weight training seems to be more effective in speed maintenance than slow-sped weight training (Liow & Hopkins, 2003).

Other studies have demonstrated that short sprint training (30 s Wingate tests) can improve anaerobic work capacity (Linossier et al, 1993). The increment in phosphorylase activity could increase the ATP supply via glycolysis facilitating a longer running time before fatigue. In addition, it has been also verified that sprint (20 to 30 s) training improves anaerobic capacity and that this improvement may be achieved through greater muscle buffering capacity (Bell & Wenger, 1988; Sharp et al, 1986). Our findings suggest that plyometric training can also be utilised to improve anaerobic capacity. Further studies are needed to determine the mechanism by which plyometric training may results in greater anaerobic capacity.

CONCLUSIONS

In summary this study shows that just 6 weeks of plyometric training with jumps results in enhanced peak power and maximal pedalling rate during cycling. Our results suggest that the anaerobic capacity could also be improved using plyometric exercises. Nevertheless, more research is needed to find out if, for example, elite cyclists could benefit from this kind of training.

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Table 1. Training program. The dropping height is indicated between brackets.

Week	Session	Drop jumps	Hurdles
1	1	4 x 5 (40cm)	4 x 5
	2	5 x 5 (40cm)	5 x 5
	3	6 x 5 (40cm)	6 x 5
2	4	5 x 5 (40cm)	5 x 5
	5	6 x 5 (40cm)	6 x 5
	6	7 x 5 (40cm)	7 x 5
3	7	5 x 5 (50cm)	5 x 5
	8	6 x 5 (50cm)	6 x 5
	9	7 x 5 (50cm)	7 x 5
4	10	6 x 5 (50cm)	6 x 5
	11	7 x 5 (50cm)	7 x 5
	12	8 x 5 (50cm)	8 x 5
5	13	6 x 5 (60cm)	6 x 5
	14	7 x 5 (60cm)	7 x 5
	15	8 x 5 (60cm)	8 x 5
6	16	7 x 5 (60cm)	7 x 5
	17	8 x 5 (60cm)	8 x 5
	18	9 x 5 (60cm)	9 x 5

Table 2. Body composition and physical characteristics (mean ± SD). Pre-T: pretraining; Post-T: post-training.

	Plyometric group		Control group	
	Pre-T	Post-T	Pre-T	Post-T
Age (years)	22.8 ± 1.7	23.1 ± 1.7	23.3 ± 1.8	23.6 ± 1.7
Body mass (Kg)	75.3 ± 10.4	75.2 ± 10.0	69.9 ± 5.0	69.6 ± 5.5
Height (cm)	173.7 ± 6.7	173.9 ± 7.0	172.9 ± 4.5	173.2 ± 4.2
Lower extremities lean mass (Kg)	19.8 ± 25.2	19.7 ± 21.5	18.5 ± 13.5	18.2 ± 12.7

Table 3. Wingate test performance prior to and following 6 weeks of either plyometric training or ussual pphysical activity (control group).

	Plyometric group (n=10)		Control group (n=7)	
	Pre-T	Post-T	Pre-T	Post-T
Peak power (W)	1023 ± 88	1066 ± 85 *	980 ± 136	968 ± 113
Mean power (W)	701 ± 47	719 ± 51 §	658 ± 61	664 ± 60
MPR (revolution.min^{-1})	121 ± 10	126 ± 10 *	121 ± 15	119 ± 11
Fatigue index (W.s^{-1})	23.3 ± 3	25.3 ± 5	22.7 ± 5 [a]	21.4 ± 4 [a]
Fatigue index- lower limb lean mass (W.s^{-1}.kg^{-1})	1.19 ± 0.19	1.28 ± 0.18	1.22 ± 0.21 [a]	1.17 ± 0.14 [a]
Fatigue index- total body mass (W.s^{-1}.kg^{-1})	0.32 ± 0.06	0.34 ± 0.04	0.33 ± 0.08 [a]	0.31 ± 0.06 [a]

* $P < 0.01$ differences within group. § $P < 0.05$ differences between groups, at the same time point. [a] (n = 6).

Effects of weight lifting combined with plyometric exercises on kicking in football, myosin heavy chain isoforms, and physical performance

Jorge Perez-Gomez, Hugo Olmedillas, Safira Delgado-Guerra, Ignacio Ara Royo, German Vicente-Rodriguez, Javier Chavarren and Jose A. L. Calbet

Department of Physical Education, University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Canary Island, Spain.

Running title: Training for kicking performance

Address Correspondence to: J.A.L. Calbet
Departamento de Educación Física
Campus Universitario de Tafira
35017 Las Palmas de Gran Canaria
Canary Islands
Spain
Fax: 34-928-458867
e-mail: lopezcalbet@terra.es

Abstract

The effects of a training program consisting in weight lifting combined with plyometric exercises on kicking performance, myosin heavy chain composition (vastus lateralis) physical fitness and body composition (DXA) was examined in 37 male physical education students divided randomly into a training group (TG: 16 subjects) and a control group (21 subjects). The TG followed 6-weeks of combined weight lifting and plyometric exercises. In all subjects tests were performed to measure their maximal angular speed of the knee during instep kicks on a stationary ball. Additional tests for muscle power (vertical jump), running speed (30-m running test) anaerobic capacity (Wingate and 300-m running tests), aerobic power (20-m shuttle run tests), were also performed. Training resulted in an increase of the peak angular velocity of the knee during kicking (+13.6%, $P<0.05$), the percentage of myosin heavy chain (MHC) type IIa (+8.4%), 1 RM of inclined leg press (ILP) (+61.4%), leg extension (LE) (+20.2%), and half squat (HQ) (+45.1%), and performance in vertical jump (all $P<0.05$). In conclusion, six weeks of strength training combining weight lifting and plyometric exercises results in significant improvement of kicking performance, as well as other physical capacities related with successes in football.

Keywords: Plyometric training, weight training, vertical jump, 1 RM, MHC

Introduction

Success in football depends among other factors (Arnason *et al.*, 2004) on kicking performance (Lees & Nolan, 1998). Although some researches have not observed an improvement in kicking performance after strength training (Trolle *et al.*, 1993; Aagaard *et al.*, 1996), most studies concluded that strength training improved kicking performance (De Proft *et al.*, 1988; Jelusic *et al.*, 1992; Dutta & Subramanium, 2002; Manolopoulos *et al.*, 2004; Manolopoulos *et al.*, 2006). Jelusic et al. (1992) found that two sessions per week of a specific stretch-shortening strength training during 15-weeks improved kicking performance in junior football players. Dutta and Subramanium (2002) also found that 6-weeks of isokinetic strength training improved performance of kicking. Manolopoulos et al. (2004) found that the velocity of the ball increased after 8-weeks of strength training combined with football training. Recently, Manolopoulus *et al*. (2006) showed that the increase in the maximum ball velocity is related with an increase of the linear velocity of the lower extremity joints. Part of the discrepancies between studies may be explained by marked differences in the strength training program. In fact, some investigators have used strength training alone (Trolle *et al.*, 1993; Aagaard *et al.*, 1996) or combined with the football-specific training (De Proft *et al.*, 1988; Manolopoulos *et al.*, 2004; Manolopoulos *et al.*, 2006), loaded kicking movements (Jelusic *et al.*, 1992; Trolle *et al.*, 1993; Aagaard *et al.*, 1996), and isokinetic strength training combined with specific training for football kicking (Dutta & Subramanium, 2002). Weight training improves maximal dynamic force and plyometric training has positive effects on speed and force of muscle contraction through its specific effect on type II fibers (Campos *et al.*, 2002; Bojsen-Moller *et al.*, 2005), although the effect of this kind of training on football performance has not been examined. Thus we hypothesised that the combination of weight lifting with plyometric training will promote an improvement is football performance but also in vertical jump and running speed, while eliciting an enhancement of type IIa myosin heavy chain composition (MHC).

Therefore, the aim of this study was to determine whether a 6-weeks strength training program combing weight lifting training and plyometric exercises elicits the appropriate adaptations to improve concomitantly kicking speed and performance in other skills relevant to football success such as: sprinting capacity, jumping and endurance. Another aim of this study was to determine is this training program has other potential beneficial effects on physical performance and body composition that could be of interest for football players.

Methods

Subjects

Thirty-seven physical educations students were randomly assigned to a strength training group (TG) (n = 16, age 23.4 ± 0.5 yr, height 174.9 ± 1.7 cm, body mass 71.2 ± 1.9 kg; mean ± SEM) and control group (CG) (n = 21, age 24.3 ± 0.5 yr, height 177.0 ± 1.5 cm, body mass 75.7 ± 2.5 kg; mean ± SEM). Subjects were informed about the aims, benefits and risks of the study, which was approved by the Ethical Committee of the University of Las Palmas de Gran Canaria and performed in accordance with the Helsinki Declaration of 1975 in regards to the conduct of clinical research. Subjects provided their written consent before participation in the study.

Training programme

The TG followed a 6-weeks training program which consisted of 3-sessions per week. During the training they executed plyometric exercises: drop jump and hurdles, 5 hurdles 1 m apart at height of 50 cm, followed by weight lifting of inclined leg press (ILP), leg extension (LE), half squat (HQ), and leg curl (LC). The intensity, repetitions and series per sessions are described in the table 1. The CG did not perform any kind of resistance training.

Tests

Lower limb lean mass

Lean mass of the lower limbs (lower limb mass – [lower limb fat mass + lower limb bone mass]) was assessed by dual-energy X-ray absorptiometry (DXA) (QDR-1500, Hologic Corp., Software version 7.10, Waltham, MA) as reported in Calbet et al. (1998) and Ara et al. (2006). DXA equipment was calibrated using a lumbar spine phantom and following the Hologic guidelines. Subjects were scanned in supine position and the scans were performed in high resolution. Lower limb lean mass (kg) was calculated from the regional analysis of the whole body scan and it has been considered equivalent to the lower limb muscle mass.

Kicking performance

A telemetric electrogoniometer (Gait Analysis System Mie Medical Ma 695110, Leeds, UK) was firmly attached to the lateral aspect of the right knee to measure angular velocity of the knee joints during maximal instep kick. In addition, an accelerometer (Kistler 8632C50 Winterthur, Switzerland) was also firmly attached to the medial aspect of the tibia, just below the tibial tuberosity and used to identify the time at which the leg impacted the football ball (Mikasa, Official size 5, Hiroshima, Japan) during kicking. The knee angular velocity reached 10 ms before the impact was taken as the maximal knee extension velocity. All data were sample at 1000 Hz and recorded on a PC using a data acquisition system (MacLab/8e, ADInstruments Pty Ltd. Castle Hill, NSW, Australia). Subjects performed three maximal instep kicks, on a stationary ball, as fast as possible without any special attention to the accuracy of the kick. The supporting leg was situated 10 cm to the side and 10 cm behind the ball. The best of the three trials was selected as the representative value of the kicking performance.

Maximal dynamic force (1 RM)

Maximal strength was assessed using the 1 RM of inclined leg press (ILP), leg extension (LE), half squat (HQ), and leg curl (LC) exercises. For the ILP and HQ, subjects were required to lower the load so that 90 degrees of knee flexion was achieved. For the LE, each participant lifted the weight to the full extension of the knee. For the LC, each subject lifted the device until contact with the thigh. Verbal signals, in all exercises, from the tester were used to encourage subjects to lift the load to the initial position. Before the first 1 RM attempt subject warmed up by doing 10 minutes of stationary cycling followed by 10 repetitions with approximately 50% of perceived maximum was performed. Then, subjects performed 2 lifts with progressively heavier weights until the 1 RM was determined. To minimise fatigue between 3- to 5-min resting periods among trials were allowed. With this procedure 1 RM was achieved with no more than 5 attempts.

Muscle biopsies

Needle muscle biopsies were obtained from the middle section of the vastus lateralis muscle under local anaesthesia. Biopsies before and after the 6-weeks period were obtained from 25 of the subjects. The muscle samples were immediately mounted with Tissue-Tek and frozen in isopentane cooled with liquid nitrogen, and stored at – 80ºC. Biopsies were obtained before and after the training period in 25 subjects. MHC analysis was performed on the muscle biopsies using sodium dodecylsulfate polyacrylamide gel electrophoresis (SDS-PAGE). From each biopsy 20-40 serial cross-sections (10 µm) were cut and placed in 200-500 µL of lysing buffer and heated for 3 min at 90ºC. Between 2 and 12 μl of the myosin-containing samples were loaded on a SDS-PAGE. Gels were run at 70 V for 43 hours at 4ºC. Subsequently, the gels were Coomassie stained and MHC isoform bands (I, IIa, IIx) was determined based on known migration patterns and quantified with Un-scan-it gel software (Orem, UT).

Vertical jump performance

The forces generated during vertical jumps were measured with a force plate (Kistler, Winterthur, Switzerland), as reported in Ara et al. (2006). During the jumps, the subjects were asked to keep their hands on the hips and to minimize horizontal and lateral displacement. They were aware that the jumps had to be executed explosively to achieve maximum height. Two kinds of jumps were performed: Squat jump (SJ), in which countermovement was not permitted, and countermovement jump (CMJ), from standing position subjects were asked to perform a countermovement, intending to reach knee bending angles of around 90º just before impulsion. A digital goniometer (Lafayette Instrument Company, Lafayette, IN) was used to verify that knees were bended at 90º before jumping for the SJ. The vertical velocity at takeoff (VT), height jumped (VJH), the mean rate of force development (RFD), positive impulse (PI), mean power (MP), maximal instantaneous power (MIP), and maximal instantaneous vertical velocity (MIV) generated were determined in the best of the three trials for SJ and CMJ. The RFD was obtained by liner regression of the force-time relationship during the impulse phase of the SJ and CMJ between 25 and 75% of the peak force.

All-out 30-s sprint test.

Wingate tests on a modified mechanically braked ergometer (Monark 818E, Monark AB, Vargerg, Sweden) equipped with a SRM power meter (Schoberer, Germany) with a braking load equivalent to 10% of body mass were completed (Calbet *et al.*, 2003).

During the Wingate tests double-toe stirrups and straps were used to tightly fix the feet to the pedals. The subjects carried out a standardized warm-up consisting of 10 minutes of continuous cycling at intensity close to 80 watts followed by 5 maximal accelerations lasting 6-s every minute since minute 6. Then the participants rested 5 minutes and performed an all-out 30-s effort with verbal encouragement. The resistance assigned for each subject was 0.1 kp per kg body weight. Peak power output (PPO) is the highest work output performed during 1 second interval of the test, and mean power output (MPO) is the average work performed during the 30 seconds both were registered.

Running sprint tests

Following an individual warm-up, subjects performed three maximal indoor short sprint trials, each separated by at least 5 minutes. The time required to cover 30-m was recorded with photoelectric cells (General ASDE, Valencia). The timer is automatically activated when the subject crosses the first cell, every 5-m thereafter. The subjects were encouraged to run as fast as they could. A standing start was used and the best of the three trials was selected as the representative value of this test. (Vicente-Rodriguez *et al.*, 2004).

Anaerobic capacity

An all-out 300-m running test was used to estimate the anaerobic capacity (Vicente-Rodriguez *et al.*, 2003). The test was performed on a 400-m track; the time was recorded manually with a digital stopwatch.

Aerobic maximal power

The maximal oxygen uptake (VO_2max) was estimated using the maximal multistage 20-m shuttle run (Leger *et al.*, 1988). Subjects were required to run back and forth on a 20-

m course and be on the 20-m line at the same time that a beep is emitted from a tape. The frequency of the sound signals increases in such a way that running speed starts at 8.5 $km \cdot h^{-1}$ and is increased by 0.5 $km \cdot h^{-1}$ each minute. The time during which the subjects were able to run for was recorded to calculate VO_2max.

Statistical analysis

Mean and standard error of the mean (SEM) are given as descriptive statistics. Differences between groups were established using Student's unpaired and paired t-test as appropriate. SPSS package (SPSS Inc, Chicago, IL) for Personal Computer was used for the statistical analysis. Statistical significance was set at $P < 0.05$.

Results

Body composition

The subject's physical characteristics are summarized in table 2. Although the enlargement in lower limb lean mass was higher in the experimental group than in control group, there was no significant difference between groups in changes in muscle mass.

Kicking performance, vertical jump and maximal dynamic force (1 RM)

Kicking performance, vertical jump and maximal dynamic force values pre and post-training are presented in table 3. Significant improvements were obtained in the maximal angular velocity of the knee in the experimental group (from 21.9 ± 1.3 before training to 24.5 ± 1.2 $rad \cdot s^{-1}$ after training, $p < 0.05$), while no significant changes in this variable were observed in the control group. However there was not correlation between the increments in angular velocity of the knee and the changes in performance in the other variables assessed in this study.

The experimental group improved also vertical velocity at takeoff (from 2.41 ± 0.03 to 2.52 ± 0.04 m/s, $p < 0.05$) and height jumped (from 0.30 ± 0.01 to 0.33 ± 0.01 m, $p < 0.05$), maximal instantaneous power (from 3341.6 ± 119.5 to 3545.3 ± 123.6 w, $p < 0.05$) achieved during the squat jumps. Strength training resulted also in improvements in countermovement jump vertical velocity at takeoff (from 2.58 ± 0.04 to 2.74 ± 0.05 m/s, $p < 0.05$), height jumped (from 0.34 ± 0.01 to 0.39 ± 0.01 m, $p < 0.05$) and maximal instantaneous vertical velocity (from 2.67 ± 0.04 to 2.80 ± 0.04 m/s, $p < 0.05$). In the same way the experimental group improved its initial values in the mechanical positive impulse (from 19.1 ± 0.5 to 20.1 0.5 kgf/s, $p < 0.05$) and maximal instantaneous power (from 3484.0 ± 114.6 to 3735.7 ± 114.4 w, $p < 0.05$). However, strength training was associated with a reduction in the rate of force development (from 843.3 ± 73.4 to 669.4 ± 72.3 kgf/s, $p < 0.05$).

The experimental group improved 1 RM performance in inclined leg press (from 203.5 ± 10.9 to 325 ± 13.8 kg, $p < 0.05$), leg extension (from 67.2 ± 3.3 to 84.3 ± 3.5 kg, $p < 0.05$) and half squat (from 145.3 ± 6.5 to 208.2 ± 7.0 kg, $p < 0.05$).

Wingate and running tests

There were no significant effects of strength training in any of the variables analysed during the Wingate tests and running test, the data are presented in table 4.

Myosin heavy chain isoforms distribution

Strength training resulted in an increase of the percentage of MHC type IIa (+8.4%, $p < 0.05$) and a reduction of the percentage of MHC type I (-5.2%, $p<0.05$) (Table 5). Prior to training a significant relationship was observed between the percentage of type I MHC and VO_2max ($r = 0.52$, $p <0.01$). No significant correlations were observed in the training group between the change in MHC type IIa composition and the improvement of kicking performance, jumping performance and maximum dynamic strength.

Discussion

The main finding of this study was that 6-weeks of strength training consisting of weight lifting combined with plyometric exercises in the same training session significantly improved kicking performance, while enhancing MHC type IIa, vertical jump and maximal dynamic force (1 RM) in physical education students.

The maximal knee angular velocities observed in this study ranged between 21.3-24.5 $rad \cdot s^{-1}$, being similar to those reported by Lees et al (2005), and a little lower than obtained by Manolopoulos et al. (2006) in football players. In general kick performance has been determined by measuring the distance reached by the ball after kicking (De Proft et. al. 1988), or by the velocity of the ball after it has been hit (Trolle et al. 1993, Aagaard et. al 1996). In theory, the velocity of the ball may vary depending on the characteristics of the ball and the technique of kicking. In addition to these factors, the kicking distance depends also on the take off angle off the ball, the direction of the wind, the density of air, and magnitude of spinning. Thus, to better isolate the effect of the strength training program on the capacity to kick harder the ball we measured the angular speed of the knee, which is the main factor determining the velocity of the ball (Dorge *et al.*, 1999; Lees & Nolan, 2002). We did not assess, however, the process of transfer of energy from proximal (upper leg) to distal (lower leg) segments which is also crucial to impel a high speed to the ball (Wickstrom, 1975; Dorge *et al.*, 1999). Isokawa and Lees (1988) observed that the velocity of the knee reached its peak between 40-70 ms after the peak hip velocity, while ankle and toe velocities obtained their peak just before impact, and 40-50 ms after the peak velocity of the knee.

Kicking performance has been related to leg muscle strength (Manolopoulos 2004, Dutta 2002, Jelusic 1992, De Proft et al. 1988). De Proft et al. (1988) noted that after a specific leg strength training program during a full football season the concentric strength of the knee increased and kick performance (measured as kicking distance) improved as well (De Proft et al. 1988). They also reported that the correlations between leg strength and kick performance improved from the beginning to the end of the season in adolescent football players. In the present investigation both kicking performance and vertical jump were improved with strength training. However, in contrast, with De Proft et al. (1988), we did not observe a significant correlation between vertical jump and peak knee angular velocity during kicking in adults.

The results of the present study are consistent with previous research in which the vertical jump performance was improved following a training program combining weight lifting and plyometric exercises (Bauer *et al.*, 1990; Adams *et al.*, 1992; Lyttle *et al.*, 1996; Fatouros *et al.*, 2000; Ingle *et al.*, 2006). The reduction in the mean rate of force development is also in agreement with previous research (Manolopoulos et al. 2004). However, despite this reduction in the RDF, mean power output was not reduced and peak power output was increased after training.

A close analysis of the effects observed in both types of jumps shows the specificity of this training program (Sale & MacDougall, 1981; Morrissey *et al.*, 1995). Training resulted in improvements of vertical velocity at take off, vertical jumping height, mechanical impulse, maximal instantaneous vertical velocity and peak power output during the countermovement jumps, while during the squat jumps significant improvements were limited to peak power output. This specificity of training is likely to be the reason why no improvements were observed in running speed or cycling power (Wingate tests) with this training program. In fact, Young et al. (2001) noted that the best training to improve the performance in 30-m was training in a similar distance without changes of directions.

Myosin heavy chain (MHC) isoforms determine the contractile and energetic properties of the human muscles fibre types (Bottinelli & Reggiani, 2000). Despite of the significant increment in MHC isoform type IIa in the experimental group there was no correlation between the increment in MCH isoform type IIa and the increment in the angular velocity of the knee, the maximal dynamic force, or height jumped. In agreement with our results, Liu et al. (2003) studied the effect of 6-weeks strength training on physical education students. Twelve subjects performed combined strength training consisting on weight lifting and plyometric exercises while the other 12 subjects only trained with weight lifting exercises Liu et al. (2003). In this study, the combined training led to a shift from I to IIa MHC. However, Raue et al. (2005) and Canepari et al. (2005) reported that the MHC distribution did not change much despite an increase in muscle strength.

In contrast with our results, Aagaard et al. (1996) and Trolle et al. (1988) did not find improvements in kicking performance after knee extension strength training. Several reasons could explain the differences; the participants of our study were physical education students while these two studies included elite football players. It is likely that football players have already a high kicking performance with less potential for improvement. Kicking incorporates a complex series of synergistic movements difficult to replicable with simple strength training movements (Bangsbo (1994). An important difference between the studies of Aagaard and Trolle with respect to Proft's study is that in Proft´s study the football players carried out the strength training in addition to their ordinary football training, while in Aagaard and Trolle studies only strength training was used. Thus, it appears that combining strength training with technical training involving the actual motor tasks is necessary to improve kicking in professional football players. Another difference between our study and Aagaard and Trolle studies was that they applied only high resistance, low resistance or loading kicking movements in the training process while we combined weight lifting with explosive actions (plyometric leg extension exercises) in the same session. Thus, the stimulus for our participants may have been higher and more specific than for the football players in Aagaard and Trolle studies. Another difference between the studies was that our participants performed maximal instep kicks as fast as possible disregarding any issue related to the accuracy or direction of the kick, while their football players shot towards a handball goal and only shots inside the goal frame were accepted, the latter may have limited their ability to use all of their kicking potential, however this fact should have affected the kick pre- and post- training similarly.

Conclusions

The present results indicate that, in physical education students, 6-weeks of strength training combining weight lifting and plyometric exercises is associated with improvements in angular velocity of the knee during a kick, the one repetition maximum (1 RM) in leg extension, inclined leg press and half squat, the vertical velocity at takeoff and height jumped in squat and countermovement jumps, beside the maximal instantaneous vertical velocity and power in the countermovement jump. This training also increased the percentage of the MHC type IIa.

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Table 1. The combined strength training program.

weeks	sessions	weight lifting (% 1RM)	series	Repetition	plyometric exercises drop Jump	hurdle
1	1	50-70-90	1-1-1	12-6-2	4 x 5 (40 cm)	4 x 5
	2	50-70-90	1-2-1	12-6-2	5 x 5 (40 cm)	5 x 5
	3	50-70-90	1-3-1	12-6-2	6 x 5 (40 cm)	6 x 5
2	1	50-70-90	1-3-1	12-6-2	5 x 5 (40 cm)	5 x 5
	2	50-70-90	1-3-2	12-8-3	6 x 5 (40 cm)	6 x 5
	3	50-70-90	1-3-1	12-8-2	7 x 5 (40 cm)	7 x 5
3	1	50-80-90	1-3-2	12-8-3	5 x 5 (50 cm)	5 x 5
	2	50-80-90	1-3-2	12-8-3	6 x 5 (50 cm)	6 x 5
	3	50-80-90	1-3-2	12-8-3	7 x 5 (50 cm)	7 x 5
4	1 TF	50-70-90	1-3-1	12-6-2	6 x 5 (50 cm)	6 x 5
	2	50-70-90	1-2-1	12-8-2	7 x 5 (50 cm)	7 x 5
	3	50-70-90	1-3-1	12-10-2	8 x 5 (50 cm)	8 x 5
5	1	50-70-90	1-3-1	12-10-2	6 x 5 (60 cm)	6 x 5
	2	50-70-90	1-3-1	12-10-3	7 x 5 (60 cm)	7 x 5
	3	50-70-90	1-3-2	12-10-2	8 x 5 (60 cm)	8 x 5
6	1	50-80-90	1-3-1	12-8-3	7 x 5 (60 cm)	7 x 5
	2	50-80-90	1-3-2	12-8-3	8 x 5 (60 cm)	8 x 5
	3	50-80-90	1-3-2	12-8-3	9 x 5 (60 cm)	9 x 5

Table 2. Subjects' anthropometrics results (mean ± SEM), body mass (BM), leg muscle mass (LM), (mean ± SEM).

Variable	Pre-test						Post-test					
	TG (n = 16)			CG (n = 21)			TG (n =16)			CG (n = 21)		
Age (yr)	23.4	±	0.5	24.3	±	0.5	23.8	±	0.5	24.7	±	0.5
Height (cm)	174.9	±	1.7	177.0	±	1.5	174.9	±	1.7	177.0	±	1.5
BM (kg)	71.2	±	1.9	75.7	±	2.5	71.9	±	1.6	76.5	±	2.4
LM (kg)	9.3	±	0.3	10.0	±	0.3	9.7♠	±	0.3	10.2♠	±	0.3
Body fat (%)	15.5	±	1.1	15.8	±	1.4	15.4	±	0.9	15.8	±	1.3

♠ $P < 0.05$ between Pre-test and Post-test

Table 3. Changes in maximal angular velocity of the knee (Kav), 1 RM of inclined leg press (ILP), leg extension (LE), half squat (HQ), and leg curl (LC), squat jump (SJ), vertical velocity at takeoff (VT), height jumped (VJH), rate of force development (RFD), positive mechanical impulse (PI), mean power (MP), maximal instantaneous power (MIP), maximal instantaneous vertical velocity (MIV), countermovement jump (CMJ), (mean ± SEM).

Variable	Pre-test						Post-test					
	TG (n = 16)			CG (n = 21)			TG (n =16)			CG (n = 21)		
Kav (rad·s^{-1})	21.9	±	1.3	22.5	±	1.0	24.5*♠	±	1.2	21.3♠	±	0.8
ILP (kg)	203.5	±	10.9	255.7*	±	16.8	325.0*♠	±	13.8	267.4♠	±	18.6
LE (kg)	67.2	±	3.3	69.8	±	2.9	84.3*♠	±	3.5	70.9	±	3.2
HQ (kg)	145.3	±	6.5	159.3	±	8.2	208.2*♠	±	7.0	155.8	±	7.2
LC (kg)	52.2	±	1.9	58.4*	±	2.2	60.5♠	±	1.8	58.7	±	2.4
SJ												
VT (m/s)	2.46	±	0.04	2.40	±	0.04	2.52*	±	0.04	2.41	±	0.03
VHJ (cm)	0.31	±	0.01	0.30	±	0.01	0.33*	±	0.01	0.30	±	0.01
RFD (kgf/s)	675.5	±	80.9	808.9	±	83.4	618.0	±	107.2	748.0	±	65.9
PI (Kgf/s)	18.0	±	0.5	18.6	±	0.6	18.5	±	0.5	18.8	±	0.5
MP (w)	633.5	±	37.5	655.6	±	27.4	631.2	±	44.3	648.3	±	28.4
MIV (m/s)	2.52	±	0.04	2.48	±	0.04	2.59	±	0.04	2.49	±	0.03
MIP (w)	3341.6	±	119.5	3471.0	±	116.0	3545.3♠	±	123.6	3504.4	±	99.6
CMJ												
VT (m/s)	2.64	±	0.05	2.56	±	0.05	2.74*♠	±	0.05	2.58	±	0.04
VHJ (cm)	0.36	±	0.01	0.34	±	0.01	0.39*♠	±	0.01	0.34	±	0.01
RFD (kgf/s)	843.3	±	73.4	741.4	±	50.1	669.4♠	±	72.3	645.0	±	54.1
PI (Kgf/s)	19.1	±	0.5	19.7	±	0.6	20.1♠	±	0.5	20.1	±	0.5
MP (w)	923.3	±	48.8	926.2	±	41.4	993.1	±	49.7	932.8	±	39.5
MIV (m/s)	2.71	±	0.05	2.65	±	0.04	2.80*♠	±	0.04	2.67	±	0.04
MIP (w)	3484.0	±	114.6	3574.3	±	115.4	3735.7♠	±	114.4	3647.6	±	101.0

♠ $P < 0.05$ between Pre-test and Post-test
*$P < 0.05$ between groups

Table 4. Peak (PPO) and mean power output (MPO) in cycle ergometer, time to cover running tests (mean ± SEM).

Variable	Pre-test						Post-test					
	TG (n = 16)			CG (n = 21)			TG (n =16)			CG (n = 21)		
Wingate												
PPO (w)	1005.1	±	21.7	1046.4	±	31.5	1025.1	±	26.6	1063.5	±	31.1
MPO (w)	703.9	±	14.4	726.7	±	17.1	737.2	±	13.3	738.3	±	18.4
Running tests												
5 (m)	1.09	±	0.01	1.12	±	0.02	1.12	±	0.02	1.12	±	0.02
10 (m)	1.84	±	0.02	1.86	±	0.02	1.86	±	0.02	1.86	±	0.02
15 (m)	2.51	±	0.02	2.54	±	0.03	2.53	±	0.02	2.54	±	0.03
20 (m)	3.13	±	0.03	3.17	±	0.04	3.15	±	0.03	3.17	±	0.03
25 (m)	3.76	±	0.03	3.77	±	0.04	3.75	±	0.03	3.77	±	0.04
30 (m)	4.35	±	0.04	4.38	±	0.05	4.34	±	0.03	4.37	±	0.04
300 (m)	46.2	±	0.5	47.1	±	0.6	46.4	±	0.7	47.4	±	0.7
VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	47.7*	±	1.4	42.9	±	1.5	46.1*	±	1.1	41.8	±	1.2

*P < 0.05 between groups

Table 5. Myosin heavy chain isoforms (mean ± SEM).

Variable	Pre-test						Post-test					
	TG (n = 15)			CG (n = 10)			TG (n =15)			CG (n = 10)		
MHC I	52.8	±	2.0	47.7	±	3.4	49.9♠	±	2.0	48.1	±	3.4
MHC IIA	46.0	±	2.0	51.0	±	3.4	49.6*♠	±	1.9	50.9	±	3.4
MHC IIX	1.2	±	0.7	1.3	±	0.8	0.5	±	0.2	0.8	±	0.5

♠ P < 0.05 between Pre-test and Post-test
*P < 0.05 between groups