TESIS DOCTORAL

DETERMINACIÓN DE LA CARGA ÓPTIMA PARA EL DESARROLLO DE LA POTENCIA MÁXIMA EN EJERCICIOS DE HALTEROFILIA.

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El Dr. Juan Carlos Redondo Castán, Profesor Titular de Universidad del Departamento de Educación Física y Deportiva de la Facultad de Ciencias de la Actividad Física y del Deporte de la Universidad de León, y el Dr. Carlos Moreno Pascual, Profesor Contratado Doctor del Departamento de Enfermería y Fisioterapia de la escuela universitaria de Enfermería y Fisioterapia de la Universidad de Salamanca.

Hacen constar:

Que la tesis doctoral titulada *“Determinación de la carga óptima para el desarrollo de la potencia máxima en ejercicios de halterofilia”* de la que es autor D. Francisco Javier Flores de Frutos ha sido realizada bajo nuestra dirección y cumple las condiciones formales y académicas exigidas por la legislación vigente para optar al título de Doctor por la Universidad de Salamanca, por lo que autorizan su presentación, mediante compendio de publicaciones, a fin de que pueda ser defendida ante el tribunal correspondiente.

Y para que así conste, y a los efectos oportunos, expedimos el presente certificado en Salamanca a 20 de diciembre de 2017.

Dr. Juan Carlos Redondo Castán   Dr. Carlos Moreno Pascual

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PUBLICACIONES

Esta tesis doctoral ha sido realizada por compendio de publicaciones. Los artículos derivados de la investigación realizada son los que se detallan a continuación:

Artículo 1

1. Flores, FJ,[1] Sedano, S,[2] de Benito, AM[3] and Redondo, JC.[4] **Validity and reliability of a 3-axis accelerometer for measuring weightlifting movements.** *Int J Sports Sci Coach*, 11(6), 872-879, 2016.
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Artículo 2

2. Flores, FJ,[1] Sedano, S[2] and Redondo, JC.[3] **Optimal load and power spectrum during jerk and back jerk in competitive weightlifters.** *J Strength Cond Res*, 31(3), 809-816, 2017.
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Artículo 3

3. Flores, FJ,[1] Sedano, S[2] and Redondo, JC.[3] **Optimal load and power spectrum during snatch and clean: differences between international and national weightlifters**. *Int J Perform Anal Sport*, 17(4), 521-533, 2017.
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Artículo 4

4. Flores, FJ, Sedano, S and Redondo, JC. **Power-Load curves in an elite weightlifter. A case study.** *Ricyde*, 50(13), 397-408, 2017.
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RESUMEN

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La habilidad para desarrollar altos niveles de potencia mecánica durante la ejecución de diferentes gestos y destrezas deportivas es considerada como un factor clave de rendimiento especialmente en aquellas modalidades que requieren la aplicación de una gran cantidad de fuerza en cortos espacios de tiempos (11, 14, 38, 66). En el estudio de los diferentes niveles de potencia mecánica generados a través de distintos ejercicios de fuerza, se ha mostrado como los ejercicios de halterofilia o levantamientos Olímpicos son los que mayores niveles de potencia mecánica son capaces de generar (2, 5, 7, 20, 22, 24, 49, 54). En este sentido, nuestros esfuerzos han estado dirigidos al estudio del desarrollo de la potencia mecánica máxima (Pmax) y, más específicamente, a la identificación de la carga óptima (Pmax load) de entrenamiento con la cual poder obtener la mejor relación entre fuerza y velocidad durante la ejecución de ejercicios Olímpicos o de halterofilia con levantadores de diferentes niveles de rendimiento, desde competidores de nivel nacional, hasta medallistas en campeonatos del mundo de halterofilia.

Para llevar a cabo este trabajo, el primero de los pasos fue el desarrollo y validación de un protocolo de medición y evaluación de ejercicios de halterofilia. Este proceso dio lugar a la primera de las publicaciones (Artículo I) donde se buscó un dispositivo (acelerómetro de 3 ejes PASCO PS-2136A) y un protocolo de medición accesible para los entrenadores desde un punto de vista económico y de desarrollo comprensible y sencillo para poder ser utilizado en el terreno deportivo de forma diaria. Comprobada la validez y fiabilidad del dispositivo y protocolo utilizados, dicha tecnología y procedimientos fueron aplicados para la realización de los estudios 2, 3 y 4, centrados ya en la determinación de la carga óptima para el desarrollo de la máxima potencia mecánica en ejercicios de halterofilia con levantadores de distintos niveles de rendimiento.

Específicamente, el objetivo del primero de los cuatro artículos publicados (Artículo I) fue la evaluación de la validez y fiabilidad de las medidas obtenidas por un acelerómetro comercial de tres ejes (PASCO PS-2136A) durante la ejecución de movimientos de halterofilia. Para llevar a cabo esta

validación se utilizó el sistema de análisis de movimiento en 3D "Vicon System", considerado uno de los métodos "gold standard" o test patrón de evaluación biomecánica. Este primer estudio de validación del acelerómetro PASCO PS-2136A sirvió como punto de partida para poder utilizar dicho dispositivo en los estudios 2, 3 y 4.

Los estudios 2 (Artículo II) y 3 (Artículo III) estudiaron cual es la carga óptima, expresada como porcentaje del 1RM (una repetición máxima), con la que se alcanzan los valores más altos de potencia mecánica en ejercicios de halterofilia, diferenciando entre levantadores de distintos perfiles de rendimiento. En ambos estudios, se llevaron a cabo dos sesiones de evaluación para cada uno de los sujetos participantes; levantadores competitivos de nivel nacional en el Artículo II y una muestra dividida en dos grupos, uno de levantadores de nivel competitivo internacional y otro de levantadores de nivel competitivo nacional en el Artículo III. En la primera de las sesiones, se determinó el 1RM inicial de los sujetos en los ejercicios de yerk y yerk tras-nuca (Artículo II) y arrancada y cargada (Artículo III). En la segunda sesión se realizó un test incremental de cargas progresivas para evaluar la potencia máxima generada a través de un espectro de cargas comprendido entre el 30% y el 90% (con incrementos del 10%) del 1RM previamente establecido en la sesión precedente para ambos ejercicios y en cada uno de los estudios.

Finalmente, el cuarto de los estudios publicados (Artículo IV) es un estudio de caso de un levantador español de alto nivel (actual récord de España en la categoría de 62 Kg en dos tiempos con 148 Kg y en total olímpico con 265 kg y ex récord de España en arrancada con 121Kg) analizando su perfil individual y comportamiento de las curvas de carga-potencia (30%-100% del 1RM) en los ejercicios ya investigados previamente en los Artículos II y III (yerk, yerk tras-nuca, arrancada y cargada).

Los principales resultados obtenidos en los estudios llevados a cabo sugieren que: el protocolo de medición y el acelerómetro comercial de 3 ejes PASCO PS-2136A validado en esta tesis en el Artículo I, puede ser un buen sistema para el registro de mediciones biomecánicas en ejercicios de halterofilia de manera sencilla, no invasiva y económica. En cuanto a la carga óptima con la que se alcanza la mayor potencia mecánica en ejercicios de halterofilia, esta se sitúa próxima al 90% del 1RM tanto para levantadores de alto nivel (nivel internacional o élite) como para levantadores de nivel competitivo nacional. Sin embargo, parece que los levantadores de mayor nivel competitivo (nivel internacional) tienden a situar la carga óptima para el desarrollo de la máxima potencia mecánica, así como el espectro óptimo de cargas, de manera más claramente localizada en la porción superior de la curva carga-potencia (80-90% del 1RM).

ANTECEDENTES

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La potencia en el deporte.

Existe un gran número de acciones deportivas que implican la realización de movimientos que requieren generar una gran cantidad de fuerza en un corto periodo de tiempo (24, 26). Algunas de estas acciones son saltos, lanzamientos, esprines, cambios de dirección… y en dichas actividades, la maximización de la potencia mecánica desarrollada es uno de los principales factores de rendimiento que determina el éxito o el fracaso en estas disciplinas (2, 10, 20, 24, 70).

Desde el punto de vista de la física, la potencia es definida como la cantidad de trabajo producido por unidad de tiempo o como el producto de la fuerza por la velocidad.

$$Potencia\ (W) = Trabajo\ (J)/Tiempo\ (s)$$

$$Potencia\ (W) = Fuerza\ (N)\ x\ Distancia\ (m)/Tiempo\ (s)$$

$$Potencia\ (W) = Fuerza\ (N)\ x\ Velocidad\ (\mathrm{m/s})$$

En el plano deportivo, la potencia generada en una acción o gesto concreto vendrá definida por el producto de la fuerza producida y la velocidad con la que se produce, siendo esta potencia máxima, cuando el producto de ambas componentes alcanza su mayor valor (9, 18, 42, 43).

Dado que la potencia es el producto de la fuerza y la velocidad, ambos componentes necesitan ser abordados en los programas de entrenamiento de aquellas disciplinas deportivas donde la producción de potencia es un factor clave del rendimiento (38). Sin embargo, cuando hablamos de acciones musculares, la curva de fuerza velocidad (C.f-v.) (Imagen 1) nos muestra cómo, fuerza y velocidad no son independientes la una de la otra, así, cuando la velocidad del movimiento aumenta la fuerza producida disminuye y viceversa (38). En este sentido, es importante señalar como dentro de la C.f-v. hay un momento en el que encontramos el valor más alto de potencia, es decir la mejor relación entre la fuerza producida y la velocidad a la que se produce (61), a este punto se le ha denominado como pico máximo de potencia (PMP) (25), umbral de rendimiento máximo (URM), al entender este como la situación en que se alcanza el máximo rendimiento mecánico en una determinada acción (25) o simplemente potencia máxima o Pmax.

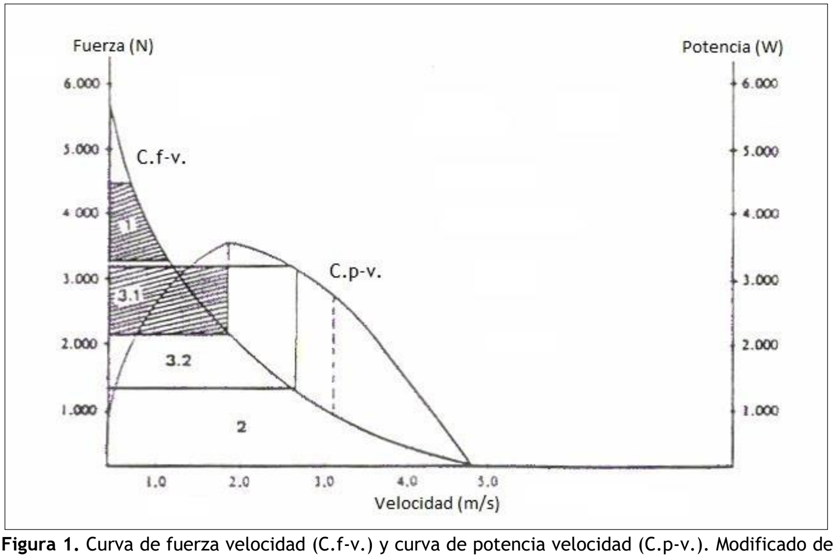

Figura 1. Curva de fuerza velocidad (C.f-v.) y curva de potencia velocidad (C.p-v.). Modificado de Tihany (68).

Desarrollo de la Potencia Máxima.

De acuerdo con Knuttgen y cols. (41) la potencia máxima se alcanza con velocidades de movimiento intermedias pero próximas a la máxima velocidad voluntaria de acortamiento muscular. En este sentido, diversos autores han expresado como la potencia máxima es alcanzada con velocidades entorno al 30% de la máxima velocidad de acortamiento muscular o con cargas próximas al 30% de la fuerza máxima isométrica (FMI) (21, 35, 36, 46, 51, 55, 69). Desde un punto de vista de operatividad y aplicación directa al campo deportivo, donde no es habitual poder medir la velocidad de acortamiento muscular o la FMI, otros autores han señalado cargas comprendidas entre el 30 y el 45% de la 1RM como porcentajes con los que se alcanza la potencia máxima en diferentes ejercicios (29, 36, 52, 54). Sin embargo, estas afirmaciones son meramente teóricas, y la experiencia y la investigación han demostrado como la potencia máxima generada en los diferentes ejercicios y gestos deportivos cambia en función de múltiples variables, como el tipo de carga, tipo de contracción o la técnica de ejecución (72).

Carga óptima para el desarrollo de la máxima potencia mecánica y espectro óptimo de cargas.

Tal y como indicábamos anteriormente, para maximizar la generación de potencia durante la consecución de cualquier gesto o acción deportiva, debe existir una relación ideal entre la producción de fuerza y la velocidad de ejecución. Consecuentemente, la carga óptima o Pmax load, es entendida como la intensidad de carga que suscita la generación de la máxima producción de potencia en un cierto movimiento (14). Desde un punto de vista práctico, la carga óptima y cargas similares entre las que no existe diferencias significativas respecto a la carga óptima es lo que se denomina espectro óptimo de cargas (OPS) (11), siendo estas consideradas como el estímulo de entrenamiento más apropiado para la mejora de la producción y desarrollo de la potencia mecánica (10, 50, 62, 66).

Tal y como señalan numerosas investigaciones (10, 50, 62, 66), existe un cierto grado de consenso en cuanto a los beneficios asociados al concepto de carga óptima para mejorar el desarrollo de potencia mecánica, sin embargo, no existe una posición clara en cuanto a cuál es la carga óptima en función del ejercicio utilizado y el tipo de población. La investigación en este sentido ha mostrado cierta controversia en cuanto al porcentaje del 1RM con el que se consigue la potencia máxima y por tanto cual es el porcentaje de carga con el que se logra alcanzar carga óptima. Así, en términos generales, y sin entrar a valorar las metodologías y muestras utilizadas, la literatura ha reportado porcentajes de carga óptima que varían en un rango desde el 0% al 90% del 1RM (3, 7, 8, 11, 15, 19, 17, 20, 24, 27, 28, 31, 32, 34, 37, 39, 40, 45, 47, 56, 57, 58, 60, 61, 64, 67, 71).

Una de las principales discrepancias en cuanto a los valores de carga óptima para alcanzar la máxima potencia mecánica viene determinada por el tipo de ejercicio utilizado (4). De forma genérica, se han estudiado 3 tipos de ejercicios con sus respectivas variantes y modificaciones. En primer lugar, ejercicios que involucran a la musculatura de las extremidades inferiores (sentadilla, media sentadilla, squat jump, prensa de pierna, extensión de rodilla…). En segundo lugar, investigaciones que involucran a la musculatura de las extremidades superiores (press de banca, el press de banca con contramovimiento, press de banca lanzando la barra…). Y, finalmente ejercicios de tipo global o poli-articulares como son los ejercicios de halterofilia o movimientos Olímpicos (arrancada, cargada, yerk, arrancada de fuerza, cargada de fuerza…).

Tanto para un tipo como otro de ejercicios, los porcentajes del 1RM reportados para alcanzar la carga óptima se han mostrado excesivamente amplios como para poder establecer conclusiones claras. En este sentido, para ejercicios de las extremidades superiores, se han reportado cargas óptimas con porcentajes comprendidos entre el 30 y el 70% del 1RM (3, 11, 19, 17, 31, 32, 34, 45, 47, 57, 60, 61). Para los ejercicios que implicaban principalmente a la musculatura de las extremidades inferiores, las cargas óptimas se han ubicado entre el 50 y el 70% de 1RM principalmente, siendo el 60% del 1RM la carga más ampliamente sugerida (31, 32, 34, 67). Aunque para ejercicios de saltos como squat jump (SJ) y counter movement jump (CMJ) este rango se amplía ubicándose entre el 0% y el 60% del 1RM (6, 8, 20, 27, 49, 50, 56, 64, 67). Y finalmente, para levantamientos Olímpicos o ejercicios de halterofilia, la carga óptima ha sido fijada normalmente con cargas entre el 70% y el 90% del 1RM (15, 24, 27, 37, 40, 58). Sin embargo, se han encontrado trabajos donde dichos porcentajes han sido significativamente inferiores, situándose desde el 30% al 60% del 1RM (39, 65, 67, 71), alimentando así la controversia en cuanto al porcentaje de carga con el que se alcanza la carga óptima con este tipo de movimientos.

Sin embargo, al comparar los resultados que se han obtenidos en los diferentes estudios e investigaciones, es importante tener en cuenta las distintas metodologías y características de los sujetos participantes en los estudios. En este sentido, parece que la carga óptima está determinada por múltiples factores como el tipo o naturaleza de los ejercicios estudiados (53, 72) el momento dentro de la preparación anual del atleta (6, 38), el bagaje o el nivel de entrenamiento de fuerza previo (7, 53). Además, esta controversia existente en cuanto a la carga óptima podría ser explicada parcialmente por las numerosas diferencias metodológicas llevadas a cabo en los estudios realizados, tales como el establecer el pico de potencia o la media de potencia (20), el equipamiento e instrumentación usado (16), la inclusión en los cálculos de la barra únicamente o de todo el sistema (atleta-barra) (48), el perfil deportivo de los sujetos evaluados (7, 53), el tipo de entrenamiento y la composición fibrilar de los deportistas (32, 59) y las capacidades técnicas de ejecución en los levantamientos o ejercicios estudiados (53).

Por lo tanto, la experiencia práctica, así como la investigación en este sentido, nos demuestra como la carga óptima para alcanzar la máxima potencia mecánica y el espectro óptimo de cargas va a depender del tipo de ejercicio y grupo muscular involucrado, de las diferencias metodológicas a la hora de hacer las evaluaciones, así como de diferentes características de los sujetos evaluados. Esta situación ha generado una gran dificultad a la hora de comparar investigaciones, lo cual se traduce en importantes discrepancias y falta de consenso entre las investigaciones que abordan esta temática.

Ejercicios de halterofilia y generación de potencia.

Como indicábamos previamente, la potencia máxima generada durante un ejercicio o acción deportiva va a diferir en función de distintas variables como son la magnitud de la carga, el tipo de contracción y la técnica de ejecución (72), pudiendo oscilar desde los 50 W generados durante los apoyos de una carrera de fondo a los más de 7000 W que se han registrado en movimientos de halterofilia (10). En uno de los primeros trabajos en esta línea, Stone y cols. (63) establecieron los valores de potencia mecánica media generada por un levantador de 100 kg de peso corporal en condiciones de competición. En dicho trabajo, se indicaron valores de 300 W durante un press de banca, 1100 W en sentadilla y peso muerto, hasta los 5400 W logrados durante el yerk y los 5500 W alcanzados durante la fase de segundo tirón para la arrancada y la cargada. Igualmente, Garhammer (24) reportó valores superiores a los 7000 W durante un intento de récord del mundo de dos tiempos con 260 kg por un levantador de 125 kg de peso corporal.

A la luz de los datos arrojados, los levantamientos Olímpicos (arrancada y dos tiempos) y variantes de los mismos (arrancada de fuerza, cargada de fuerza, yerk tras-nuca…), se encuentran entre los medios más empleados para la mejora de la producción potencia en numerosos deportes (12, 13). El ejercicio de yerk, así como la fase de segundo tirón durante la arrancada y la cargada son conocidos por ser los movimientos donde mayores niveles de potencia mecánica se es capaz de generar de todos los ejercicios con resistencias (2, 5, 7, 20, 22, 24, 49, 54), por tanto, los ejercicios de halterofilia son considerados como uno de los mejores medios para mejorar e incrementar los niveles de producción de potencia mecánica (44).

Así, los levantamientos Olímpicos son considerados como uno de los medios de entrenamiento más útiles para maximizar el rendimiento en pruebas o modalidades deportivas donde la generación de altos niveles potencia mecánica es un factor determinante del rendimiento deportivo (23, 24, 26), además, son los movimientos específicos de un deporte concreto, la halterofilia.

Formulación e identificación del problema.

Dado que el control de la carga es esencial para asegurar la especificidad y adaptaciones del entrenamiento (33), y la carga óptima para alcanzar la máxima potencia mecánica es específica de cada ejercicio (62), es importante que los entrenadores y atletas sean conscientes de cuál es la carga óptima y el espectro óptimo de cargas con ejercicios de levantamiento Olímpicos o ejercicios de halterofilia. Además, podríamos decir que esta importancia es superior cuando se trata de estos ejercicios, ya que son los ejercicios que mayores niveles de potencia son capaces de producir y por tanto, son uno de los mejores medios de entrenamiento para el desarrollo y mejora de la producción de potencia (44). Pero la gran complejidad técnica que presenta la ejecución correcta de los ejercicios de halterofilia hace necesario que se identifiquen también las posibles diferencias en cuanto a la carga óptima y el espectro óptimo de cargas, dependiendo del nivel de rendimiento de los deportistas, así como de la calidad de la ejecución técnica de los movimientos. Ante estos hechos, y teniendo en cuenta que pocas investigaciones se han centrado en este aspecto (24), consideramos que sería interesante determinar cuál es la carga óptima para alcanzar la máxima potencia mecánica en ejercicios de halterofilia con una muestra con un amplio bagaje en el campo de la fuerza, y más concretamente con ejercicios Olímpicos, como son halterófilos o levantadores de diferentes niveles competitivos, desde competidores de nivel nacional hasta medallistas en campeonatos internacionales.

Además, desde un punto de vista práctico y de orientación al trabajo de campo, el poder medir la potencia máxima alcanzada durante la ejecución de ejercicios de halterofilia en su lugar habitual de entrenamiento de forma precisa y no en condiciones de laboratorio, permitiría a los entrenadores facilitar e implementar sus estrategias de entrenamiento mejorando la eficacia de los programas de entrenamiento planteados con el fin de aumentar el nivel competitivo de sus deportistas. En este sentido, según Abernethy y cols. (1) el primer factor que determina una correcta planificación del entrenamiento de fuerza en el deporte es la disposición de instrumentos válidos y fiables para controlar, medir y monitorizar la fuerza y la potencia. Así, la validación de herramientas de bajo costo y fácil manejo, así como protocolos de medición adecuados que puedan ser utilizadas por los entrenadores y atletas sin la necesidad de acudir a costosos laboratorios de investigación a los que no siempre se tiene acceso, permitiría un importante salto cualitativo en cuanto a la optimización del entrenamiento deportivo.

OBJETIVOS E HIPÓTESIS

OBJETIVOS E HIPÓTESIS

Objetivos

Se plantea como objetivo general el siguiente:

- Determinar cuál es la carga óptima para el desarrollo de la máxima potencia mecánica en diferentes ejercicios de halterofilia y con levantadores de distintos niveles de rendimiento.

Y como objetivos específicos:

- Validación de un protocolo de medición mediante un acelerómetro comercial de bajo coste (PS-2136A, PASCO, Roseville, CA) que facilite la labor de los entrenadores para el control y valoración de diferentes parámetros cinéticos y cinemáticos en ejercicios de halterofilia.

- Determinar la carga óptima y el espectro óptimo de cargas requerido para desarrollar la máxima potencia mecánica en los ejercicios de yerk y yerk tras-nuca con levantadores de nivel competitivo nacional.

- Determinar la carga óptima y el espectro óptimo de cargas requerido para desarrollar la máxima potencia mecánica en los ejercicios de arrancada y cargada diferenciando los resultados obtenidos entre levantadores de nivel internacional o élite y levantadores de nivel competitivo nacional.

- Examinar la curva de carga-potencia en los ejercicios de arrancada, cargada, yerk y yerk tras-nuca en un halterófilo español de nivel internacional, actual poseedor de los récords de España absolutos de dos tiempos y total Olímpico en la categoría de peso corporal de 62 Kg.

Hipótesis

La hipótesis general de este proyecto de tesis doctoral defiende:

- Por un lado que; el acelerómetro comercial de bajo coste Pasco PS-2136A, (Roseville, CA) puede ser un instrumento adecuado para medir y controlar la potencia generada durante los ejercicios de halterofilia.

- Y por otro lado que; la carga óptima para el desarrollo de la máxima potencia mecánica será alcanzada con porcentajes próximos al 1RM del sujeto durante los ejercicios de halterofilia, variando este porcentaje en función del ejercicio y del nivel deportivo o de rendimiento de los levantadores.

Para lograr cada uno de los objetivos descritos anteriormente y comprobar las hipótesis planteadas, se realizaron cuatro investigaciones fruto de las cuales se han publicado los cuatro artículos que forman el compendio de publicaciones de esta tesis doctoral. Dichos artículos son:

- **Artículo 1. VALIDITY AND RELIABILITY OF A 3-AXIS ACCELEROMETER FOR MEASURING WEIGHTLIFTING MOVEMENTS.**

- **Artículo 2. OPTIMAL LOAD AND POWER SPECTRUM DURING JERK AND BACK JERK IN COMPETITIVE WEIGHTLIFTERS.**

- **Artículo 3. OPTIMAL LOAD AND POWER SPECTRUM DURING SNATCH AND CLEAN: DIFFERENCES BETWEEN INTERNATIONAL AND NATIONAL WEIGHTLIFTERS.**

- **Artículo 4. POWER-LOAD CURVES IN AN ELITE WEIGHTLIFTER. A CASE STUDY.**

PUBLICACIONES

Artículo I.

VALIDITY AND RELIABILITY OF A 3-AXIS ACCELEROMETER FOR MEASURING WEIGHTLIFTING MOVEMENTS.

Resumen Artículo I.

VALIDITY AND RELIABILITY OF A 3-AXIS ACCELEROMETER FOR MEASURING WEIGHTLIFTING MOVEMENTS.

VALIDEZ Y FIABILIDAD DE UN ACELERÓMETRO COMERCIAL DE 3 EJES PARA MEDIR MOVIMIENTOS DE HALTEROFILIA.

Objetivo/s:

El propósito de este estudio fue evaluar la validez y la fiabilidad de las medidas obtenidas por un acelerómetro comercial de 3 ejes (PS-2136A, PASCO, Roseville, CA) durante la ejecución de ejercicios de halterofilia.

Metodología.

Sujetos

Participaron en este trabajo once atletas hombres (5 lanzadores de jabalina, 3 lanzadores de peso y 3 lanzadores de disco) experimentados con la ejecución de ejercicios Olímpicos o movimientos de halterofilia (12.45 ± 3.85 años de experiencia). Todos los sujetos participaban en competiciones nacionales en sus respectivas pruebas.

Procedimiento

Cada uno de los deportistas que conformaron la muestra realizó tres intentos en cada uno de los tres ejercicios evaluados (arrancada de fuerza, cargada de fuerza, y yerk desde soportes) con diferentes cargas comprendidas entre el 30% y el 90% de su 1RM, previamente medido para cada deportista en cada ejercicio.

Material

Las medidas obtenidas por el acelerómetro comercial de 3 ejes PS-2136A, PASCO, (Roseville, CA) fueron comparadas con el sistema de análisis del movimiento en 3D Vicon (Oxford, UK) como test patrón.

Resultados.

Validez

Los resultados obtenidos y comparados entre el acelerómetro analizado (PS-2136A, PASCO, Roseville, CA) y el criterio de referencia (Vicon, Oxford, UK) mostraron una adecuada concordancia entre ellos sin revelar diferencias estadísticamente significativas ($p>0,05$) entre los dos sistemas de medición utilizados. Pero esta concordancia, para los tres ejercicios estudiados, se observa exclusivamente en el eje vertical (Z) y tomando la fase de tirón (primer tirón, fase de transición y segundo tirón) para los ejercicios de arrancada de fuerza y cargada de fuerza y hasta el punto más alto alcanzado por la trayectoria de la barra antes de la posición de recepción en el yerk (flexión, extensión y split),

Fiabilidad

Los datos obtenidos mostraron una fiabilidad casi perfecta (ICC>0,9) para el protocolo desarrollado y ejercicios aplicados.

Conclusiones.

El acelerómetro de 3 ejes estudiado (PS-2136A, PASCO Roseville, CA) ha sido validado satisfactoriamente en el eje vertical (eje Z) durante la fase de tirón en los ejercicios de arrancada y cargada de fuerza y hasta el punto más alto alcanzado por la trayectoria de la barra antes de la recepción o fijación de la barra en el ejercicio yerk (incluyendo las fases de flexión, extensión y split). El dispositivo validado es sencillo de usar y manejar además de tener un bajo coste comercial lo cual facilita su acceso a entrenadores para su trabajo diario de campo fuera de un entorno de laboratorio. Sin embargo, los datos obtenidos deben ser cuidadosamente interpretados ya que se obtuvieron bajas correlaciones con los datos aportados por los ejes X e Y.

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Validity and reliability of a 3-axis accelerometer for measuring weightlifting movements

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Abstract

The purpose of the current study was to assess the validity and reliability of measures obtained by a 3-axis commercial accelerometer during weightlifting movements in comparison with kinematic data derived from the 3D videography. Kinematic data from 3D videography were obtained from 11 track & field throwers performing 3 trials each one at different loads in power snatch, power clean and jerk from the rack. The results showed that the accelerometer measures were highly correlated with derived acceleration data from 3D videography data in the vertical plane (Z axis) taking up to the pull phase (including first pull, transition and second pull) for power snatch and power clean and up to the highest point of the bar path before the catch position (including dip, drive and split phases) for jerk from the rack. On the basis of these results, this device was proven to be valid and reliable on Z axis on the weightlifting movements studied. Thus, this system may be a useful and easy to handle tool to measure acceleration during real-time training sessions.

Keywords

Barbell acceleration, explosive weightlifting, high speed video, motion analysis, track and field athletics

Introduction

Weightlifting is an official sport in which athletes attempt to lift as much weight as possible in the snatch and clean & jerk exercises.[1] The snatch and clean & jerk are the 2 lifts contested in the sport of weightlifting. The snatch is the first lift performed in competition and clean & jerk lift is the second which is divided in two parts; clean phase and jerk phase. These exercises, their variations and the methods used in the sport of weightlifting are also applied as a method of strength training for a wide range of other sports such as basketball, volleyball, football, track and field[2] and strength and conditioning programs.[3] Weightlifting movements are considered some of the best training exercises to maximize dynamic athletic performance and their kinetic and kinematic characteristics are specific to many athletic skills.[4]

Weightlifting exercises, including their variations (power clean, power snatch high pulls...), have been studied for a long period of time[5,6] and over the past few years biomechanical characteristics of weightlifting exercises have been widely investigated. [4–10] The main goals of these kind of investigations were to determine how the kinetic and kinematic variables influence success in weightlifting and to find out the best technique in these exercises.[3,4,8,10]

However, Stone et al.[6] reported great technical variability among weightlifters increasing the difficulty of prediction of weightlifting performance. To achieve a better understanding of weightlifting technique and the kinetic and kinematics of barbell acceleration may be helpful for coaches. Furthermore, very little information exists about the barbell acceleration during

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weightlifting movements and their variations.[7,8,11,12] Although the barbell acceleration is not extensively analyzed, this factor is highly important in weightlifting movements insofar as it is directly proportional to force applied to the barbell while mass is a constant value.[8,9]

Barbell acceleration has been used to indicate fatigue[7–9] and to calculate force and power.[8,9] Therefore, in order to achieve a better understanding of the technique and to assess biomechanical characteristics responsible for performance in weightlifting, the development and use of any technology to carry out these goals may be desirable.[7–9]

Recently, accelerometers have been shown to be a potential tool for evaluating and monitoring weightlifting performance.[7–9] Price, size, portability and easy use are some of the advantages of accelerometers in comparison with other device.[13] Thus, accelerometers may be considered a reasonable alternative to solve some limitations mentioned above and assess weightlifting movements[7,8] and the athletic performance.[13–15] Triple-axis accelerometers are the most advanced devices of this type of technology. They can be coupled to the barbells and have the potential to offer accelerations in the 3 planes of motion[14] allowing a global evaluation of the movement although bearing in mind that during the weightlifting movements the barbell rotation can cause issues for accelerometers.[16] Moreover, to mate an accelerometer to the barbell without lift disturbance in the athlete may be able to offer an instantaneous visual feedback to coaches and athletes.[7,8] Although visual feedback is not a newfangled practice per se, its practical use has been limited by the cost or portable access to involve these tools in field tests.[16]

Sato et al.[7] previously tested the validity of the PS 2119 accelerometer (PASCO, Roseville, CA) in the pull phase (portion of the snatch and clean in which the barbell is displaced from the floor to achieve the greater vertical displacement) of weightlifting movements. This tool is the previous version of the accelerometer used in the current research (PS-2136A, PASCO, Roseville, CA). Although PS2119 accelerometer was previously validated in 2D, we do not know if the information provided by each one of the three axes of motion is valid and reliable in analyzing every axis separately. Therefore, the purpose of this study was to determine the validity and reliability of the accelerometer PS-2136A in each plane of motion during weightlifting exercises. 3D motion-analysis system was used as a gold standard reference to determine the validity and reliability of the accelerometer studied (PS2136A). Our hypothesis was that the accelerometer analyzed would exhibit good validity and reliability during the pull phases (including first pull, transition and second pull) of the power snatch and power clean and up to the highest point of the bar path before the catch position (including dip, drive and split phases) of the jerk in each one of the three planes of motion compared with the gold standard used.

Methods

Subjects

Eleven male subjects were recruited to participate in this study. All subjects had an extensive background in strength and power training using weightlifting movements (12.45 ± 3.85 years of experience). All of them competed at the national level on their respective track and field events during the 2014 and 2015 seasons. The sample included 5 javelin throwers, 3 shot putters and 3 discus throwers. Prior to participation in the study, all subjects read and signed an informed consent in accordance with guidelines set by the Human Subjects Review Committee at University of Salamanca. Table 1 shows the descriptive characteristics of the subjects.

Materials

A 3-axis accelerometer (PS-2136A, PASCO, Roseville, CA) was utilized in the current research. This device is an altimeter plus accelerometer, but the altimeter function was overlooked in the current investigation. This accelerometer is factory calibrated and the standard configuration of the device allows recording acceleration values in the X, Y, and Z planes of motion. The accelerometer is coupled to a wireless device (Airlink 2 PS-2010, PASCO, Roseville, CA), which transmits the data to a laptop computer. Table 2 shows the physical

Table 1 Descriptive data for participant characteristics *(M ± SD)*.

	Male ($n = 11$)
Age (years)	27.47 ± 3.61
Height (cm)	188.05 ± 8.76
Body mass (kg)	97.36 ± 8.73
Strength and power training experience (years)	12.45 ± 3.85

Table 2 Physical characteristics of the accelerometer and Bluetooth wireless device.

	3-axis PS-2136A	Airlink 2 PS-2010	Both device mated
Weight (Kg)	0.080	0.050	0.13
Width (cm)	3.8	3.8	3.8
Length (cm)	2	2	2
Depth (cm)	8.8	9	17.6

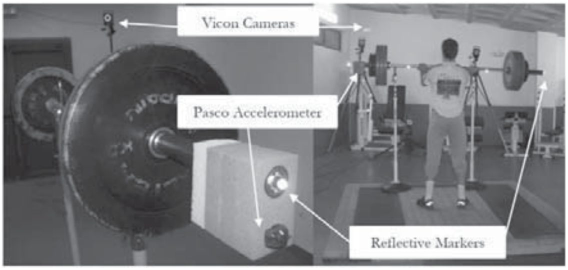

Figure 1 — System for acceleration assessment.

characteristics of the accelerometer and Bluetooth wireless device.

The sampling rate of the accelerometer was 100 Hz. Previous studies showed that 100 Hz is an appropriate sampling rate to record weightlifting exercises.[7,8] The measuring device was placed on the barbell by the foam unit shown in Figure 1 according to the specifications set by Sato et al.[7] This padded mount provided sufficient protection for the accelerometer absorbing the shock of dropping the bar on the lift platform.[7] The total mass of the measuring device plus the protection foam was 0.180 Kg, which is equivalent to a lightweight spring-type collar device.[7] This weight is not enough to induce asymmetric disturbances during the lift. The accelerometer unit was placed underneath and in line with the long axis of the barbell on the left edge of the bar in relation to the lifter's position (Figure 1). In that position, bar movements forward-backward, side to side and up-down are equivalents to X, Y and Z axis according to the factory configuration. The sensor unit position was checked according to the position described above before each attempt.

A three-dimensional motion analysis system (Vicon, Oxford, UK) consisted of seven VICON-460 infrared video cameras was utilized to track the trajectories of 4 markers (25 mm reflective markers) attached to the bar. Two markers at the edges of the bar and two more markers on the middle part of the bar near the snatch grip were placed (Figure 1 shows the position of the markers). The cameras sampled at a rate of 100 Hz.[7,17] This configuration allowed synchronization of video frames with acceleration values. Vicon system was calibrated according to the manufacturer's instructions prior to each data collection session.

A High-speed video camera (Casio Exilim, EX-F1, Tokyo, Japan) was positioned at a distance of 5 m in front of the barbell and lifter. The camera operated at 100 Hz to capture the barbell trajectory. This camera was used to allow a simple synchronization between accelerometer and 3D analysis system. The highest point of the bar's path was utilized taking as a reference the left end reflective marker, for event synchronization.

Data collection and processing were performed using Pasco Capstone software (Version 1.1.5, Pasco Scientific PASCO, Roseville, CA) and Vicon Nexus motion-capture software (Nexus 1.8.3, Vicon, Oxford, UK) for accelerometer and 3D device respectively.

Testing Procedures

After a warm-up similar to their weightlifting session, subjects randomly performed 3 sets of 1 repetition with different loads, ranging from 30 to 90% of 1RM, using loads between 50 kg to 140 kg. The recovery set was determined by the athlete, timed between 3 and 5 minutes. This protocol was followed in the three exercises assessed, the order of the exercises was: power snatch, power clean and jerk from the rack. Every subject was instructed to perform each lift as they routinely perform it, being very important do not rotate the bar just before the lift because the sensor's measures are directionally dependent. Any power snatch and power clean received in a squat position with the upper thigh below parallel to the floor was ruled unsuccessful.

Hook grip, weightlifting belt, weightlifting shoes and chalk were allowed to use by the subjects. Weightlifting straps were not allowed. In both testing sessions strong verbal encouragement was given to all subjects to motivate them to perform each lift as maximally and as powerfully as possible to maximize performance.

The three different instruments used in this work (accelerometer, 3D System and high speed video camera) recorded simultaneously each barbell movement. In any case, full movements were recorded. Nevertheless, bearing in mind that the turnover and recovery phase on power snatch and power clean usually cause accelerometer rotation[7] data obtained (full movement) should be divided into two phases: the first one until the highest point of the pull phase (second pull) starting from the ground (in power snatch and power clean) or from the rack up to the highest point of the bar path before the catch position (in jerk) and the second one the remainder.

Statistical Analyses

SPSS statistical software package (version 18.0; SPSS, Inc., Chicago, IL, USA) was used to analyze all data. Normality of the distribution was tested by means of the Kolmogorov-Smirnov test. Concurrent (criterion-related) validity of the accelerometer system was assessed using one-way ANOVA by comparing each selected measure (Pasco) with criterion (Vicon). According to Drouin et al.[18] the discrepancy between these measures was assessed for all trials performed by calculating the method error (ME) and the coefficient of variation of the method error (CV_{ME}). Calculated method error represents the variation (standard deviation) of the delta scores generated from two separate measures of the same variable. To represent this standard deviation appropriately it must be presented as a value normalized to the mean of the delta scores.[19] Therefore, to reflect the amount of variation in the difference scores between test measures, the coefficient of variation of method error (CV_{ME})[19] was calculated. Pearson product-moment correlation coefficient (r) was used to determine the specific relationship within each trial for the accelerometer and criterion accelerometer data. The reliability was investigated using intraclass correlation coefficients ($ICC_{2,1}$), ranging from "questionable" (0.7 to 0.8) to "high" (>0.9)[20] with 95% CI[21] and the associated standard error of measurement (SEM) for each ICC was also calculated.[21] Magnitude of effect within exercises was estimated with Cohen's effect size (ES). Cohen classified ES into "small" (0.2 – 0.3), "medium" (0.4 – 0.7), and "large" (> 0.8)[22]. The α level was set at 0.05.

Results

Validity

Table 3 reports one-way ANOVA analysis, method error (ME), coefficient of variation of the method error (CV_{ME}) and Pearson product-moment correlation coefficient (r) for each phase, axis and exercise. For all exercise, but exclusively for Z-axis, the results of acceleration demonstrate a good agreement between accelerometer and criterion measures because analysis of variance no revealed significant differences ($p > 0.05$) between Pasco and Vicon. Regarding the coefficient of variation, the scientific literature suggests it should be fewer than 10%, although these estimates have been a source of discrepancy.[23–25] The degree of discrepancy was negligible (CV_{ME} range: 1.13% – 1.88%) and would not threaten the credibility of Pasco measures in certain phases of the exercises.

In this sense, focusing on up to pull phase for power snatch ($p = 0.480$) and power clean ($p = 0.242$) and for jerk ($p = 0.302$) up to the highest point of the bar path before the catch position, the CV_{ME} observed (Table 3) between Pasco and Vicon was 1.38%, 1.44% and 1.13% (for power snatch, power clean and jerk respectively), the method error across all trials was 3.94 m/s^2, 4.02 m/s^2 and 3.35 m/s^2, respectively and Pearson correlation coefficients showed to be the highest in the 3 movements ($r = 0.841$; $r = 0.882$ and $r = 0.933$, respectively). Focusing on from pull phase to finish of the movement for power snatch and power clean and for jerk from the highest point of the bar path before the catch position to finish, the analysis of variance revealed significant differences ($p < 0.05$) between Pasco and Vicon in the 3 movements. Finally, with regard to the full movement, the CV_{ME} observed was 1.48%, 1.70% and 1.88% (respectively),the method error across all trials was 3.99 m/s^2, 4.36 m/s^2 and 3.37 m/s^2 (respectively) and Pearson correlation coefficients pointed out high correlations in the 3 movements ($p = 0.171$, $r = 0.841$; $p = 0.499$, $r = 0.882$ and $p = 0.086$, $r = 0.933$, respectively).

Reliability

Because of the results achieved in the validity, Table 4 only reports intraclass correlation coefficients for trial reliability (ICC), standard error of measurement (SEM) and magnitude of effect (ES) for the exercises analyzed focusing on up to pull phase for power snatch and power clean and for jerk up to the highest point of the bar path before the catch position and only for Z axis. Registered data demonstrated near perfect reliability ($ICC > 0.9$) for each technique. So the accelerometer is capable of providing accurate data.

Discussion

The results support the authors' hypotheses that the accelerometer studied provides valid and reliable measurements of acceleration data, however this validation should be only considered taking into account the vertical data (Z axis).

Past studies have tried to identify key components of weightlifting through kinetic and kinematic variables under competition[10,12,26,27] and training[8,9] conditions and during laboratory researches.[7] According to Sato et al. [7] the biomechanical characteristics collected in the laboratory are usually accessible after a data processing

Table 3 Concurrent validity of Pasco and Vicon for acceleration estimation.

			One-way ANOVA				
Exercise.	Phase	Axe	*F*-value	*p*	r	ME	CV_{ME} (%)
POWER SNATCH	up to pull phase	X	46.651	0.000	0.502*	3.18	2.77
		Y	19.818	0.000	0.076*	5.13	2.36
		Z	0.498	0.480	0.841*	3.94	1.38
		Resultant	6172.189	0.000	0.627*	1.98	2.38
	from pull phase to finish	X	60.608	0.075	0.033*	2.73	1.13
		Y	2.278	0.131	0.185*	0.97	1.30
		Z	54.881	0.000	0.723*	1.15	1.20
		Resultant	11144.617	0.000	0.048*	2.06	1.37
	full movement	X	24.28	0.000	0.324*	3.26	1.82
		Y	17.981	0.000	0.128*	5.08	1.54
		Z	6.472	0.171	0.814*	3.99	1.48
		Resultant	12194.593	0.000	0.551*	2.07	1.35
POWER CLEAN	up to pull phase	X	18.035	0.000	0.452*	3.60	1.55
		Y	59.211	0.000	0.047*	5.59	1.33
		Z	1.372	0.242	0.882*	4.02	1.44
		Resultant	5376.657	0.000	0.573*	1.98	1.32
	from pull phase to finish	X	9.684	0.000	0.068*	2.52	1.20
		Y	68.550	0.000	0.131*	0.90	1.33
		Z	7.535	0.000	0.727*	1.37	1.24
		Resultant	5579.983	0.000	0.381*	1.91	1.33
	full movement	X	26.848	0.000	0.347*	4.19	1.68
		Y	125.048	0.000	0.083*	6.20	1.66
		Z	0.457	0.499	0.773*	4.36	1.70
		Resultant	9901.115	0.000	0.530*	1.98	1.49
JERK	up to catch position**	X	220.747	0.000	−0.001	1.90	1.46
		Y	0.371	0.543	0.056*	4.25	1.23
		Z	1.068	0.302	0.933*	3.35	1.13
		Resultant	7359.248	0.000	0.598*	1.40	1.16
	from catch position **to finish	X	188.121	0.000	0.017	2.05	1.07
		Y	2.227	0.136	0.106*	1.34	1.85
		Z	25.398	0.000	0.736*	1.10	1.20
		Resultant	7713.893	0.000	0.229*	1.70	1.37
	full movement	X	406.321	0.000	0.006	2.72	1.55
		Y	0.633	0.426	0.090*	4.64	1.72
		Z	9.033	0.086	0.888*	3.67	1.88
		Resultant	12156.683	0.000	0.531*	1.56	1.34

*$p < 0.05$, r = Pearson correlation coefficient, ME = method error, CV_{ME} = coefficient of variation of method error
**The highest point of the bar path before the catch position

and not immediately after the execution attempt. Two previous research papers used the accelerometer employed in the current study taking advantage of data obtained in real time.[8,9] In both investigations, the authors pointed out the importance of being able to show an instant feedback after each movement.

However, the results of the current research suggest that one should be careful interpreting the feedback offered by this device in the three axes of movement because outcomes reported only significate correlations in the Z axis (vertical plane) showing poor Pearson coefficient for the X and Y axes. Although positive agreements between the measures of accelerometer studied and the gold standard used were found taking into account the acceleration data of full movement in the exercises investigated, according to our results and

Table 4 Reliability assessed using intraclass correlation coefficients and standard errors of measurement on Z axis.

	ICC	95% CI	SEM	ES
POWER SNATCH (up to pull phase)	0.952	0.932–0.966	1.77	0.000
POWER CLEAN (up to pull phase)	0.963	0.945–0.975	1	0.001
JERK (up to catch position**)	0.990	0.985–0.993	0.55	0.023

CI = confidence interval; ICC = intraclass correlation coefficient; SEM = standard error of measurement; ES = Cohen's effect size
**the highest point of the bar path before the catch position

Sato et al.[7] these agreements are due to the inclusion of data up to pull phase (power snatch and power clean) and up to the highest point of the bar path before the catch position (jerk).

As previously noted by Sato et al.[7] the PS 2119 accelerometer is directionally dependent of its position, just as the case with the current model analyzed in this work (PS-2136A). Due to this fact it is required to eliminate the data obtained in those phases in which the accelerometer varies its initial position during the exercise (turnover and recovery phase for power snatch and power clean and catch and recovery phase for jerk from rack).

According to this, our study suggests that only the data obtained in the vertical plane (Z axis) and up to the pull phase for the power snatch and power clean and up to highest point of the bar path before the catch position during jerk from the rack could be considered valid with the device studied. This supports previous research by Crewther et al.[14] who pointed that bar movements on the horizontal plane could be a source of errors, especially during free weights exercise. Therefore, we disagree with the authors[8,9] who reported the convenience of training resultant acceleration values to assess weightlifting movements using the previous version of the accelerometer studied.

Garhammer[17] pointed out that weightlifting movements have a very small horizontal component that can be neglected. In the same line, Kraemer and Fleck[28] reported that if the horizontal movement from the center is less than 7%, this effect can be ignored. Therefore, according with these authors the information of vertical plane provided by the accelerometer studied could be useful for coaches and lifters to control the weightlifting performance.

This research, similar to Sato et al.[7] suggests that one of the major limitations of the accelerometer is the device's orientation which must be constant throughout the movement to avoid misrepresentation of the data. For this reason, as we already previously commented, data obtained of some phases (the turnover and recovery phase on power snatch and power clean and catch and recovery phase on jerk) should be removed taking only data up to the pull phase for power snatch and power clean and up to the highest point of the bar path before the catch position for jerk. Consequently, the chances to assess the entire movement are restricted. On the other hand, data obtained in the pull phase offers an important tool to develop weightlifting training and test process.[2,29,30]

Finally, it should be mentioned the necessity to protect the device against the external shocks of this type of exercises.[7] The users must be aware of the importance to keep safe the system with some kind of foam that prevents tool damage and misrepresentation of the data. The protection system used in this research (Figure 1) was homemade attaching shower's sponges. This system has demonstrated enough protection for the device, but because the sensor is directionally dependent, a spotter (partner or coach) should replace the system before each repetition. This must be considered as a limitation of the device.

In summary, there are numerous ways of quantifying sport performance, from sophisticated and expensive laboratory tests to low-cost and less-precise field tests. Although laboratory test conditions are frequently well controlled and gold standard methods are used to test the sport performance, the field tests are often more practical, relevant, sport specific and preferred by coaches and athletes. The 3 axis commercial accelerometer validated in the present study may be a useful piece of equipment to measure barbell acceleration in weightlifting movements in comfortable field areas.

Monitoring biomechanical variables like acceleration could provide a deeper understanding of weightlifting performance, but coaches and biomechanists must be cautious with the suitability of the devices used and the interpretation of the data obtained. The accelerometer tested appears to provide validated acceleration data on the Z axis (vertical plane) being necessary to reject acceleration data reported in X and Y axes. This information would allow coaches to make proper decisions and become more sophisticated in the training processes. However coaches and athletes must be aware of limitations of the device for measuring other than the vertical plane.

An additional application of this validation could be the assessment of other variables from acceleration value. This one provides an interesting visual feedback and a proper tool to control weightlifting performance, but other biomechanical data like force or power output could also be calculated using this value. In that sense Thompson and Bemben[31] showed that velocity and power calculated from accelerometers can provide useful and reliable results.

Conclusion

The 3-axis accelerometer (PS-2136A, PASCO, Roseville, Calif.) has been validated with satisfactory results in the vertical plane (Z axis) up to pull phases (including first pull, transition and second pull) in power snatch and power clean and up to the highest point of the bar path before the catch position (including dip, drive, and split phase) in jerk from the rack. This system could be used multiple times per season even in every weightlifting training, being easy to handle and cost effective tool by coaches and athletes. However the acceleration data obtained of X and Y axes must be interpreted with cautions since they presented lower correlations.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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References

1. Lloyd RS, Oliver JL, Meyers RW, et al. Long-term athletic development and its application to youth weightlifting. *Strength Cond J* 2012; 34(4): 55–66.
2. Haff G, Whitley A, McCoy L, et al. Effects of different set configurations on barbell velocity and displacement during a clean pull. *J Strength Cond Res* 2003; 17(3): 95–103.
3. Comfort P, McMahon JJ and Fletcher C. No kinetic differences during variations of the power clean in inexperienced female collegiate athletes. *J Strength Cond Res* 2013 Feb; 27(2): 363–368.
4. Comfort P, Allen M and Graham-Smith P. Kinetic comparisons during variations of the power clean. *J Strength Cond Res* 2011; 25(12): 3269–3273.
5. Otto WH, Coburn JW, Brown LE, et al. Effects of weightlifting vs. kettlebell training on vertical jump, strength, and body composition. *J Strength Cond Res* 2012; 26(5): 1199–1202.
6. Stone MH, Pierce KC, Sands WA, et al. Weightlifting: a brief overview. *Strength Cond J* 2006; 28(1): 50–66.
7. Sato K, Smith SL and Sands WA. Validation of an accelerometer for measuring sport performance. *J Strength Cond Res* 2009; 23(1): 341–347.
8. Sato K, Fleschler P and Sands WA. Barbell acceleration analysis on various intensities of weightlifting. In: *Annual Conference of the International Society for Biomechanics in Sports*, Limerik, Irland 2009.
9. Sato K, Sands WA and Stone MH. The reliability of accelerometry to measure weightlifting performance. *Sports Biomech* 2012; 11(4): 524–531.
10. Kipp K, Harris C and Sabick M. Correlations between internal and external power outputs during weightlifting exercise. *J Strength Cond Res* 2003; 27(4): 1025–1030.
11. Enoka RM. The pull in Olympic weightlifting. *Med Sci Sports* 1979; 11(2): 131–137.
12. Kipp K and Harris C. Patterns of barbell acceleration during the snatch in weightlifting competition. *J Sports Sci* 2015; 33(14): 1467–1471.
13. Sell TC, Akins JS, Opp AR, et al. Relationship between tibial acceleration and proximal anterior tibia shear force across increasing jump distance. *J Appl Biomech* 2014; 30(1): 75–81.
14. Crewther B, Kilduff L, Cunningham D, et al. Validating two systems for estimating force and power. *Int J Sports Med* 2011; 32(4): 254.
15. Comstock BA, Solomon-Hill G, Flanagan SD, et al. Validity of the Myotest(R) in measuring force and power production in the squat and bench press. *J Strength Cond Res* 2011 Aug; 25(8): 2293–2297.
16. Sakadjian A, Panchuk D and Pearce AJ. Kinematic and kinetic improvements associated with action observation facilitated learning of the power clean in Australian footballers. *J Strength Cond Res* 2014; 28(6): 1613–1625.
17. Garhammer J. A review of power output studies of Olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *J Strength Cond Res* 1993; 7(2): 76–89.
18. Drouin JM, Valovich-mcLeod TC, Shultz SJ, et al. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol* 2004; 91(1): 22–29.
19. Portney LG and Watkins MP. *Foundations of clinical research: applications to practice*. New Jersey: NJ, Prentice Hall Upper Saddle River, 2000.
20. Vincent W and Weir J. *Statistics in kinesiology*. Leeds, United Kingdom: Human Kinetics, 1999.
21. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 2005; 19(1): 231–240.
22. Cohen J. *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Earlbaum Associates, 1988.
23. Atkinson G and Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 1998; 26(4): 217–238.
24. Cronin JB, Hing RD and McNair PJ. Reliability and validity of a linear position transducer for measuring jump performance. *J Strength Cond Res* 2004; 18(3): 590–593.
25. Garnacho-Castaño MV, López-Lastra S and Maté-Muñoz JL. Reliability and validity assessment of a linear position transducer. *J Sports Sci Med* 2015; 14(1): 128.

26. Szyszka P and Mastalerz A. The relationship between biomechanical indicators of the snatch technique and female weightlifters' levels. *Pol J Sport Tourism* 2014; 21: 218–222.
27. Lin Y, Hsu C and Ho W. Performance Evaluation for Weightlifting Lifter by Barbell Trajectory. Performance Evaluation. *Int J Med H Biomedical Pharm Engi* 2015; 9: 193–196.
28. Kraemer WJ and Fleck SJ. *Optimizing strength training: designing nonlinear periodization workouts*. Leeds, United Kingdom: Human Kinetics, 2007.
29. Hadi G, Akkus H and Harbili E. Three-dimensional kinematic analysis of the snatch technique for lifting different barbell weights. *J Strength Cond Res* 2012; 26(6): 1568–1576.
30. Kipp K, Redden J, Sabick M, et al. Kinematic and kinetic synergies of the lower extremities during the pull in Olympic weightlifting. *Journal Appl Biomech* 2012; 28: 271–278.
31. Thompson CJ and Bemben MG. Reliability and comparability of the accelerometer as a measure of muscular power. *Med Sci Sports Exerc* 1999; 31(6): 897–902.

Artículo II.

OPTIMAL LOAD AND POWER SPECTRUM DURING JERK AND BACK JERK IN COMPETITIVE WEIGHTLIFTERS.

Resumen Artículo II.

OPTIMAL LOAD AND POWER SPECTRUM DURING JERK AND BACK JERK IN COMPETITIVE WEIGHTLIFTERS.

CARGA ÓPTIMA Y ESPECTRO ÓPTIMO DE CARGAS EN LOS EJERCICIOS DE YERK Y YERK TRAS-NUCA CON HALTERÓFILOS COMPETITIVOS.

Objetivo/s.

El propósito de este estudio fue determinar la carga óptima y el espectro óptimo de cargas requerido para alcanzar la máxima potencia mecánica en los ejercidos de yerk y yerk tras-nuca con levantadores competitivos de nivel nacional.

Metodología.

Sujetos

Trece hombres, halterófilos experimentados, participaron en el presente estudio. Todos estaban competitivamente activos en el momento de participar en el estudio, siendo 8 de ellos medallistas en sus respectivas categorías de peso corporal en alguno de los Campeonatos de España de Halterofilia 2014 o 2015 o en ambos. De acuerdo a su mejor rendimiento deportivo el coeficiente Sinclair medio acreditado por estos deportistas en el momento de participar en el estudio fue de 302,52 ± 37,57 puntos.

Procedimiento

En este estudio, se realizaron dos sesiones de evaluación. En la primera de ellas se determinó el 1RM de los sujetos en los ejercicios de yerk y yerk tras-nuca. Y en la segunda sesión se realizó un test incremental de cargas progresivas para evaluar la potencia máxima generada a través de un espectro comprendido entre el 30 y el 90% (con incrementos del 10%) del 1RM previamente establecido en la sesión precedente para ambos ejercicios.

Material

Durante la segunda de las sesiones de evaluación (test incremental de cargas), se utilizó el acelerómetro de 3 ejes PS- 2136A (PASCO Scientific, Roseville, CA, USA) conectado vía Bluetooth a un ordenador portátil y operando a 100 Hz, para la recolección de datos y posterior estudio de los mismos. La validez de dicho dispositivo fue comprobada previamente comparado las mediciones aportadas por el acelerómetro con el test patrón o criterio de referencia (VICON SYTEM).

Resultados.

El pico de potencia obtenido con cada una de las cargas evaluadas incrementó desde el 30 hasta el 90% del 1RM alcanzando el mayor nivel (carga óptima) con el 90% del 1RM tanto en el yerk como en el yerk tras-nuca. El ejercicio de yerk tras-nuca obtuvo valores de potencia pico más altos que el yerk en todo el espectro de cargas evaluado, pero no se encontraron diferencias significativas entre ellos. Comparando la carga óptima (90% del 1RM) con el resto de las cargas evaluadas en el espectro estudiado, se observaron diferencias estadísticamente significativas con todas las cargas a excepción del 80% del 1RM. Así, la carga con la que se alcanzó los mayores niveles de potencia (carga óptima) y el espectro óptimo de cargas para ambos ejercicios fue alcanzado con el 90% del 1RM y ubicado entre el 80 y el 90% del 1RM.

Conclusiones.

Los resultados de este estudio revelan como la intensidad relativa (expresada como porcentaje del 1RM) influye de forma diferente sobre la producción de potencia durante los ejercicios de yerk y yerk tras-nuca. Desde un punto de vista práctico, la carga con la que se maximiza la producción de potencia (carga óptima) y cargas similares, entre las cuales no existen diferencias estadísticamente significativas entre ellas (espectro óptimo de cargas), son consideradas como el estímulo más apropiado para mejorar la producción de potencia en un gesto específico. En el presente estudio se localizó la carga óptima en el 90% del 1RM y el espectro óptimo de cargas entre el 80% y el 90% del 1RM tanto para el yerk como en el yerk tras-nuca. Basados en los hallazgos de esta investigación, se recomienda que los halterófilos competitivos de nivel nacional programen cargas comprendidas entre el 80% y el 90% de su 1RM cuando deseen mejorar la producción de potencia en estos ejercicios. Además, y en referencia a aquellos sistemas de entrenamiento en los cuales no se utiliza el ejercicio de yerk tras-nuca, (filosofía búlgara) sería interesante el utilizar este ejercicio cuando se busquen alcanzar altos niveles de producción de potencia ya que los valores reportados en este ejercicio fueron superiores a los del yerk en todas las cargas evaluadas.

OPTIMAL LOAD AND POWER SPECTRUM DURING JERK AND BACK JERK IN COMPETITIVE WEIGHTLIFTERS

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ABSTRACT

Flores, FJ, Sedano, S, and Redondo, JC. Optimal load and power spectrum during jerk and back jerk in competitive weightlifters. *J Strength Cond Res* 31(3): 809–816, 2017—Although the ability to develop high levels of power is considered as a key component of success in many sporting activities, the optimal load (Pmax load) that maximizes power output (Pmax) remains controversial mainly during weightlifting movements. The aim of the present study was to determine Pmax load and optimal power spectrum (OPS) required to elicit Pmax by comparing jerk and back jerk exercises in competitive weightlifters. Thirteen male competitive weightlifters participated in 2 testing sessions. The first session involved performing one repetition maximum (1RM) in the back jerk and jerk and the second session assessed a power test across a spectrum of loads (30–90%) of each subject's 1RM in the predetermined exercises tested. Relative load had a significant effect on peak power, with Pmax load being obtained at 90% of the subjects' 1RM in both exercises assessed. There was no significant difference between the power outputs at 80% of 1RM compared with 90% of 1RM. Furthermore, Pmax load and OPS were the same for jerk and back jerk, whereas peak power in the back jerk demonstrated no significant increases in every load of the power-load curve. We can conclude that it may be advantageous to use loads equivalent to 80–90% of the 1RM in jerk and back jerk in competitive weightlifters when training to maximize power.

KEY WORDS peak power, Pmax load, Pmax, weightlifting

INTRODUCTION

Weightlifting exercises are one of the most effective ways to develop power output (26). Weightlifting exercises, including snatch, clean, and jerk, and variations of these exercises, are known to produce some of the highest average human power outputs of all resistance training exercises (14,20,23,25,31). To achieve a high level of performance, weightlifting exercises and their derivatives are generally used as training exercises in many sports (18,21) and conditioning programs (7,8).

The snatch and clean and jerk are the 2 lifts contested in the sport of weightlifting. The snatch is the first lift performed in competition and clean and jerk lift is the second which is divided in 2 parts: clean movement and jerk movement. In the jerk movement, large loads are accelerated rapidly (37) through ranges of motion that are mechanically similar to those in many sporting skills (15), achieving a power output value in this movement that is far in excess of those obtained during classic resistance exercises (14,25,31,33). On these lines, Stone et al. (31) reported that a 100-kg male weightlifter produced 5,400 W of power output during the jerk in weightlifting competition, a much higher value than the 1,100 and 300 W achieved by the same lifter in the squat and bench press, respectively, although that low values reported for the squat and bench press would be influenced by the methods used to calculate power. Similarly, Garhammer (14) reported almost 7,000 W during the clean pull in an attempt at a world record with 260 kg by a weightlifter of 125 kg of body weight. The second pull of snatch and clean is known to elicit the greatest amount of power output of all resistance exercises (8,11,14,31), whereas jerk and second pull power output values are usually found to be very similar in magnitude for elite lifters in top physical condition (14,34). These values and data suggest that the jerk movement might be an excellent exercise for achieving a high level of power output and improving muscular power.

Most of the world's weightlifting training programs are derived from models developed by the weightlifting federations of Bulgaria and the former Soviet Union (16). The Bulgarian philosophy uses a limited battery of 6 exercises (snatch, clean and jerk, power snatch, power clean and jerk, front squat, and back squat) in the weightlifting training. However, the Soviet system uses a greater variety of exercises, including the back jerk or jerk behind the neck (16). The back jerk is an exercise commonly included in weightlifting training programs not influenced by the Bulgarian

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methodology of training weightlifters, being the primary assistance exercise for improving the jerk phase of clean and jerk (16).

The jerk is performed starting with the barbell held firmly on the shoulders (on the lifter's anterior deltoids and below the head), so during the drive phase, the athlete must do a rapid neck extension to keep the bar's path as vertical as possible while avoiding hitting the chin with the barbell. However, the back jerk is started with the barbell on the shoulders and upper back (as in the back squat position); in this way, the trajectory of the barbell upward has no obstacles. In this context, the lower limb kinematics on the propulsion phase during the jerk and back jerk is very similar but because of the differences on the starting position of the barbell, there may be some kinematics differences. However, these differences have never been explored though could affect the training recommendations related with power profiles.

To maximize the power output during any exercise, there must be a compromise between force and velocity. Consequently, the optimal load (Pmax load) is the load intensity that elicits maximal power production in a certain movement (12). From a practical point of view, Pmax load and similar loads with no significant differences between them (optimal power spectrum, OPS) (5) are considered the most appropriate stimulus to improve the power developed in a specific technical gesture (28). According to previous researches related to weightlifting exercises (snatch, clean, jerk, and variations of these movements), the center of gravity of the barbell and that of the system (bar plus body mass) do not move in parallel (9–11,19,20,24,27). So, the success during weightlifting exercises is directly dependent on the capacity to move an external object as fast as possible, applying the maximum power to the barbell (17,20,27). Because the peak power attained varies with different relative loads (22,23), it is crucial that the load-power relationships of the jerk and back jerk should be examined to establish training recommendations for the use of these exercises.

The importance of power production has been reported as a key factor in weightlifting where the success depends on how much weight the athlete can lift (1RM) and not how much power the athlete can produce. In that sense, Stone et al. (33) claimed that power production is the most significant factor in determining success in weightlifting, and likewise, Hori et al. (18) indicated that the success of weightlifting depends on the power applied to the barbell against high loads (high-load speed strength). According to previous studies (14,33), during weightlifting, Pmax load is achieved with high loads; therefore, Pmax load is a key factor to achieve success during these types of exercises.

Although the jerk has been included in weightlifters' and athletes' strength and conditioning programs (23) and the back jerk is a common exercise used by many weightlifters, no previous investigations have simultaneously compared the Pmax load in jerk and back jerk. Hence, the aim of this investigation was to find Pmax load and OPS required to elicit Pmax during the jerk and back jerk in a group of competitive weightlifters, comparing the differences between exercises. In line with previous research findings (14,33), it was hypothesized that Pmax load during jerk and back jerk exercises would be achieved toward the heavier end of the load-power curve (70–80% of 1RM), with the highest Pmax being achieved in the back jerk exercise.

Methods

Experimental Approach to the Problem

In this study, 13 competitive and experienced male weightlifters were tested in 2 sessions. The objective of the first testing session was to determine the subject's 1RM for the back jerk and jerk. During the second testing date, subjects were required to perform a power test across a spectrum of loads (30–90%) of their predetermined 1RM, with 1 attempt at each load to help identify the optimal load (Pmax load) and OPS for maximal power output (Pmax).

Subjects

Thirteen experienced male weightlifters participated in the study. All the subjects were active in competitive weightlifting during the 2015 season, 8 of them being medalists in their respective body-weight categories in the Spanish National Championships of 2014, of 2015, or both. On the basis of their best weightlifting performance in competition, their Sinclair coefficient was 302.52 ± 37.57 (30). The descriptive characteristics of the subjects are shown in Table 1. Before participating in the study, all the participants read and signed an informed consent statement in conformity with guidelines set by the local ethics committee. The study conformed to the principles of the World Medical Association's Declaration of Helsinki.

Procedures

Two test sessions were carried out in the weightlifters' usual training environment to assess 1RM and power. Before the start of each test session, participants went through a standardized 20-minute warm-up. In both sessions, the order of the exercises assessed was back jerk followed by jerk, and 10-minute rest was allowed between exercises. This

Table 1. Descriptive data for participant characteristics (mean ± *SD*).

	Male (n = 13)
Age (y)	25.94 ± 6.87
Height (m)	174.65 ± 3.27
Body mass (kg)	72.15 ± 9.88
Sinclair coefficient	302.52 ± 37.57
Weightlifting experience (y)	13.46 ± 8.20

Figure 1. Weightlifter perform the lift with the accelerometer fixed to the bar according to the study by Sato et al. (29).

recovery period is similar to that applied in weightlifting competitions between the snatch and the clean and jerk movements.

1RM Testing. The subjects' 1RM was obtained for the back jerk and jerk following the standardized protocol presented by Baechle and Earle (1). The barbell was taken out of power rack before starting each exercise. The weightlifters had previously performed this test numerous times in conjunction with their normal training program for the purpose of monitoring strength development and therefore were well accustomed to the procedures for the test.

Power Testing. Two to 4 days after their 1RM was established, a power test session was performed. After the warm-up exercise sets, subjects carried out a maximum effort repetition for each load, which was systematically increased to 30, 40, 50, 60, 70, 80, and 90% of the subject's predetermined 1RM. The recovery period between loads was determined by the athlete but was in all cases between 3 and 5 minutes.

A 3-axis accelerometer (PS-2136A; PASCO Scientific, Roseville, CA, USA) operating at 100 Hz, and a Bluetooth wireless device (Airlink 2 PS-2010; PASCO Scientific) was used in the power testing. This accelerometer was chosen for its easy portability in the weights room and minimal disturbance of the flow of the lifting sessions without compromising the weightlifter's technique in data collection (29). The measuring device was attached to the barbell with the foam unit shown in Figure 1 according to the specifications set out by Sato et al. (29). The total mass of the measuring device plus the protective foam was 180 g, which is equivalent to a metal barbell collar (29). This weight is not enough to induce asymmetric disturbances during a lift. The accelerometer unit was placed underneath and in alignment with the long axis of the barbell on the left edge of the bar in relation to the lifter's position (Figure 1). In that position, backward-and-forward, side-to-side, and up-and-down bar movements are equivalent to the x, y, and z axes, respectively, in accordance with the factory configuration. Before each attempt, the position of the sensor unit was checked and if necessary restored to the configuration described above.

Concurrent (criterion-related) validity of the accelerometer system was assessed using 1-way analysis of variance (ANOVA) by comparing each selected measure with criterion, a 7 VICON-460 infrared video camera at 100 Hz (Vicon, Oxford, United Kingdom). According to Drouin et al. (13), the discrepancy between these measures was assessed for all trials performed by calculating the method error (ME) and the coefficient of variation of the method error (CV_{ME}). Exclusively for z axis, the results of acceleration demonstrate a good agreement between accelerometer (Pasco) and criterion measures (VICON) because ANOVA revealed no significant differences ($p > 0.05$) between them ($CV_{ME} = 1.13\%$). Furthermore, the reliability was investigated using ICC (2,1), and the associated standard error of measurement (*SEM*) for each ICC was also calculated (36). Finally, registered data demonstrated near-perfect reliability

TABLE 2. Descriptive data for power for jerk and back jerk for each test occasion.*

	Peak power (W)		95% confidence interval	
Load (% 1RM)	Jerk	Back jerk	Lower bound	Upper bound
30	1,165.42 ± 279.95†		996.24	1,334.59
		1,420.65 ± 535.71†	1,080.27	1,761.02
40	1,652.66 ± 458.83†		1,375.39	1,929.93
		1,801.09 ± 572.37†	1,437.42	2,164.75
50	2,145.61 ± 504.13†		1,840.97	2,450.26
		2,383.58 ± 690.40†	1,944.91	2,822.24
60	2,493.72 ± 622.50†		2,117.55	2,869.89
		2,817.45 ± 629.55†	2,417.46	3,217.45
70	2,838.00 ± 606.48†		2,471.51	3,204.50
		3,022.95 ± 714.33†	2,569.09	3,476.82
80	3,019.66 ± 629.08		2,639.51	3,399.81
		3,248.44 ± 737.84	2,779.64	3,717.24
90	3,103.34 ± 616.87		2,730.57	3,476.10
		3,400.22 ± 691.07	2,961.14	3,839.31
Exercise (*F*)	1.11 ($p = 0.303$; ES = 0.046)			
% of 1RM (*F*)	301.75 ($p < 0.001$; ES = 0.929)			

*Values are given as mean ± *SD*.
†Significantly different ($p < 0.001$) from 90% of 1RM.

(ICC = 0.990; *SEM* = 0.55). So the accelerometer is capable of providing accurate data.

The data were processed thereafter, using Pasco Capstone software (Version 1.1.5; PASCO Scientific), and barbell peak power outputs were calculated from acceleration according to the methodology explained by Thompson and Bemben (35). Data analysis included only the vertical acceleration attained by the barbell that was lifted, but only up to the highest point of the bar path before the catch position of the exercises assessed. It should be noted that the lifter's body weight was not included in the calculations, so that the power calculations recorded the work done against the bar by the lifter. The exclusion of the body weight in the calculations gives more important information about weightlifting performance because the success of weightlifting depends on the power applied to the barbell, which moves independently of the body and how high the lifter can pull (in the snatch and clean) or drive (in the jerk) the barbell regardless of the lifter's body mass (19,20,22,27). In that sense, to measure specifically, the power applied to the barbell may be the primary outcome measure when assessing weightlifting performance (19,20,22,27).

To ensure the maximum effort from subjects for every load, in both testing sessions strong verbal encouragement was given to all participants to motivate them to perform each lift to the maximum and as powerfully as possible.

Statistical Analyses

The SPSS statistical software package (version 18.0; SPSS, Inc., Chicago, IL, USA) was used to analyze all data. Normality of distribution was tested by means of the Kolmogorov-Smirnov test. Standard statistical methods were used to calculate the mean and *SD*. Power-related effects and the differences between exercises were assessed using 2-way ANOVA with repeated measures (exercise × load). When a significant *F* value was achieved through Wilks' lambda, Scheffe's post hoc procedures were performed to locate the pairwise differences. The Bonferroni correction for multiple comparisons was applied. The significance level was set at 0.05. Effect size (ES) statistics was assessed using Cohen's *d* (6). Cohen classified ESs as "small" (0.2–0.3), "medium" (0.4–0.7), and "large" (>0.8). In addition, for the power output of each exercise, the reliability of measurements was calculated using the ICC.

RESULTS

The Kolmogorov-Smirnov test suggested that all variables were distributed normally ($p > 0.05$). Jerk and back jerk peak power increased from 30 to 90% of 1RM. Table 2 shows the data for both exercises in every test. The ICC was 0.97 for jerk and 0.89 for back jerk. The back jerk elicited a greater peak power than the jerk for all the loads assessed (Figure 2), but ANOVA revealed no significant exercise × load interaction effects for them ($F = 1.111$; $p = 0.303$). Pmax occurred at a relative intensity of 90% of 1RM for the jerk (3,103.34 ± 616.87 W) and the back jerk (3,400.23 ± 691.07 W). However, these were not significantly different from the peak power produced with 80% of 1RM for the jerk (3,019.66 ± 629.08 W; $p > 0.05$, ES = 0.06) and 80% of 1RM for the back jerk (3,248.4 ± 737.84 W; $p > 0.05$, ES = 0.11). Therefore, the

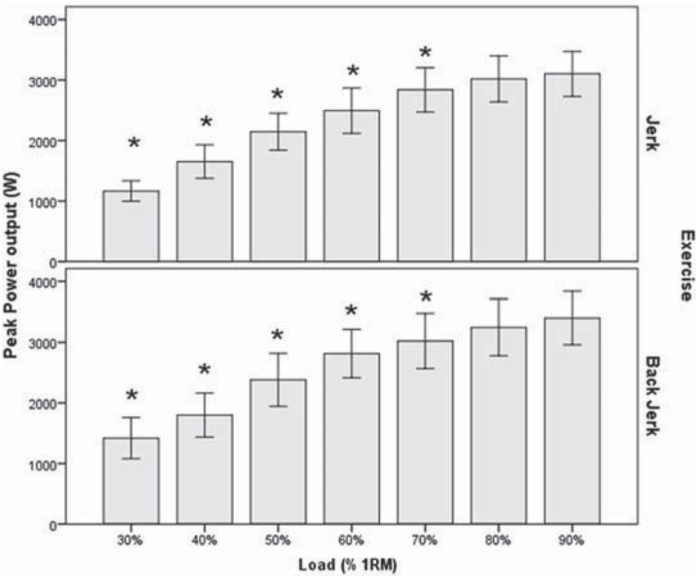

Figure 2. Peak power output at loads of 30–90% of one repetition maximun (1RM) during jerk and back jerk. *Significantly different from 90%.

Pmax load (optimum load) and OPS in both exercises were achieved with 90% of 1RM and between 80 and 90% of 1RM.

For the jerk, Scheffe's post hoc tests revealed differences between 90 and 30% ($p < 0.001$, ES = 4.04), 40% ($p < 0.001$, ES = 2.66), 50% ($p < 0.001$, ES = 1.70), 60% ($p < 0.001$, ES = 0.983), and 70% ($p < 0.001$, ES = 0.71). However, for the back jerk, the differences were noted between 90 and 30% ($p < 0.001$, ES = 3.20), 40% ($p < 0.001$, ES = 2.52), 50% ($p < 0.001$, ES = 1.47), 60% ($p < 0.001$, ES = 0.88), and 70% ($p < 0.001$, ES = 0.53).

Discussion

The purpose of this research was to determine the optimal load (Pmax load) to achieve maximal peak power output (Pmax) and the OPS in the jerk and back jerk exercises in competitive weightlifters. In this particular population, the Pmax load was achieved at 90% of 1RM for both exercises tested. However, the load of 80% of 1RM was not statistically different compared with 90% identifying the OPS between loads of 80 and 90% of 1RM for both lifts (Figure 2 and Table 2).

Training in weightlifting focuses on generating high levels of muscular power during the lift and to transfer that power to the bar in a short period (4). During weightlifting exercises, such as snatch, clean, jerk, and variations of these movements, the center of gravity of the barbell and that of the system (bar plus body mass) do not move in parallel (9–11,19,20,24,27). According to this, a weightlifter's interest is moving an external object, the bar plus weight, as fast as possible because the success of weightlifting depends on the power applied to the barbell (17,20,27). Taking into account only the power applied to the barbell, Pmax load during weightlifting exercises and their derivatives have been reported ranging from 80 to 100% of 1RM (17,20). The results obtained in the current study using back jerk and jerk located Pmax load at 90% of 1RM and the OPS at the top of the power load curve, between 80 and 90% of 1RM. It would seem that to date nobody has attempted to establish the Pmax load and OPS for jerk and back jerk exercises. Thus, the results obtained in this work confirm the trend shown in the literature (14,33) toward achieving Pmax load with a high percentage of 1RM during weightlifting exercises and their variations.

In the present study, Pmax load was achieved with a 90% of 1RM in the jerk and back jerk. Although no previous pieces of research have tested these exercises, the high percentages found in the present study might be influenced by the strength profile of the subjects (competitive weightlifters). Thus, it has been suggested that the level of experience and proficiency of the subject could be expected to shift the percentage of maximum strength at which the highest power is produced either upward or downward (23). In this way, the strength level of the subjects might be a factor that makes matters less clear (25). For example, in line with the current study, Stone et al. (32) found that in squat jumps, weaker subjects produced the maximal power output at a lower relative load than did stronger. The same trend was reported by Kilduff et al. (25) using hang power clean exercises with professional rugby players. However, there is no uniform agreement between researchers, and contradictory results were reported by Baker et al. (2,3), suggesting that stronger athletes used lower percentages of 1RM than weaker to maximize power output during jump squats and bench press throws.

The Pmax obtained in the present work are significantly lower than those previously reported by Stone (31) or Garhammer (14). These discrepancies might be attributable to variations in the methodological procedures used (10,11,19,20,27,33), like how to collect and analyze power output, the body mass of the subjects, and the conditions for data collection. In the current study, the body mass of the sample was 72.15 ± 9.88 kg, in comparison with the 100 and 125 kg of the weightlifters studied by Stone (31) and Garhammer (14), respectively. In addition, the methodology used in these works to estimate the Pmax was video analysis under competition conditions, unlike to the evaluation carried out in training conditions in the current study. According to Garhammer (14), horizontal component during the jerk is negligible for skilled lifters, so the jerk analysis of Garhammer only included the work done vertically on the barbell and center of mass (CM) of the lifter. Thus, during the current study, horizontal work was rejected; however, the power output because of lifting body's CM was not included in the present study. The power output because of lifting body's CM during the study by Garhammer (14) was 689 W, which accounted for 15% of total power generated by the lifter (4,570 W). These methodological differences could well be decisive in explaining the variability reported in the power values in these studies.

The results of the present study, taken together with the details given above, suggest that weightlifting movements and their variations (including jerks and back jerks) require a higher percentage of loads to maximize power output. According to Lake et al. (26), this might be explained by the fact that, although ballistic, load projection must be performed under control and within technical patterns, which may prevent achieving maximum power outputs with lighter loads.

As hypothesized, the results of the present research noted that the back jerk elicited a greater peak power than the jerk for all the loads assessed (Figure 2). As it was previously indicated, this may be explained by the nature of the movement involved developing high force and high velocity (9–11), with no obstacles during the trajectory of the barbell upward permitting to apply greater power values in a movement with easier technical patterns than the jerk. Under the influence of Bulgarian method (16), the back jerk is not usually an exercise scheduled in many weightlifting training programs, but according to our results, the back jerk can be considered as valid as the jerk to improve power development. Moreover, the back jerk is one of the best variations among weightlifting exercises to improve the jerk phase of clean and jerk (16).

The findings of this study should be considered in light of a few limitations. First, the peak power is referred only to the bar, although according to McBride et al. (27), little differences exists whether calculating the bar, body, or system (lifter-plus-bar) power during weightlifting movements. Second, the findings of this study are mainly applicable to sports where to move an external mass as fast as possible is the main goal (e.g., throwing or weightlifting); thus, it does not apply to other sports like sprinting or jumping (27), in which power production against one's own body is crucial to achieve high performance. And finally, power against 100% of 1RM was not assessed so we cannot conclude definitely that 90% is the Pmax load. Future studies may identify roundly the Pmax load, including the evaluation power at 100% of 1RM.

In conclusion, the results of this study provided new information about mechanical power output during jerk and back jerk exercises. They indicated that relative intensity had a significant effect on peak power during the jerk and the back jerk, and that Pmax were obtained working against an external load equivalent to 90% of 1RM. Furthermore, they identified OPS between 80 and 90% of 1RM in both exercises. In addition, future studies should consider differences either from other weightlifting exercises (e.g., snatch, clean power snatch, or power clean) carried out by the same group of subjects or from the same exercises undertaken by other athletes (e.g., sprinters, jumpers, or throwers). Likewise, it would be worth exploring how the kinematic differences observed between jerk and back jerk may affect the kinetic values. These would provide helpful knowledge for athletes and coaches so that they could improve performances.

Practical Applications

It is important for coaches to be aware of the Pmax load for peak power production and OPS. The results of this study indicate that the Pmax during jerk and back jerk is maximized with a resistance of 90% of 1RM, with the OPS between loads of 80 and 90% in both lifts. The findings showed that peak power in the back jerk is higher than in the jerk across the whole spectrum of loads, suggesting the use of back jerk in the battery of training exercises for competitive weightlifters, focusing on improving their muscular power production and clean and jerk performance. Therefore, because no statistically significant differences in peak power were noted between 80 and 90% of 1RM, when setting out training programs to improve the power output, it is suggested that loads between 80 and 90% of 1RM in the jerk and the back jerk may be the most advantageous to improve power production during the exercises assessed by the weightlifters.

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References

1. Baechle, TR and Earle, RW. Essentials of strength training and conditioning. Champaign, IL: Human Kinetics, 2008.
2. Baker, D, Nance, S, and Moore, M. The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *J Strength Cond Res* 15: 92–97, 2001.
3. Baker, D, Nance, S, and Moore, M. The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *J Strength Cond Res* 15: 20–24, 2001.
4. Campos, J, Poletaev, P, Cuesta, A, Pablos, C, and Carratala, V. Kinematical analysis of the snatch in elite male junior weightlifters of different weight categories. *J Strength Cond Res* 20: 843–850, 2006.
5. Castillo, F, Valverde, T, Morales, A, Pérez-Guerra, A, De León, F, and García-Manso, J. Maximum power, optimal load and optimal power spectrum for power training in upper-body (bench press): A review. *Rev Andal Med Deporte* 5: 18–27, 2012.
6. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, NJ: Laurence Erlbaum Associates, 1988.
7. Comfort, P, Allen, M, and Graham-Smith, P. Comparisons of peak ground reaction force and rate of force development during variations of the power clean. *J Strength Cond Res* 25: 1235–1239, 2011.
8. Comfort, P, McMahon, JJ, and Fletcher, C. No kinetic differences during variations of the power clean in inexperienced female collegiate athletes. *J Strength Cond Res* 27: 363–368, 2013.
9. Cormie, P, McBride, JM, and McCaulley, GO. Validation of power measurement techniques in dynamic lower body resistance exercises. *J Appl Biomech* 23: 103, 2007.
10. Cormie, P, McBride, JM, and McCaulley, GO. The influence of body mass on calculation of power during lower-body resistance exercises. *J Strength Cond Res* 21: 1042–1049, 2007.
11. Cormie, P, McCaulley, GO, Triplett, NT, and McBride, JM. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc* 39: 340, 2007.
12. Cormie, P, McGuigan, MR, and Newton, RU. Developing maximal neuromuscular power. *Sports Med* 41: 17–38, 2011.
13. Drouin, JM, Valovich-mcLeod, TC, Shultz, SJ, Gansneder, BM, and Perrin, DH. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol* 91: 22–29, 2004.
14. Garhammer, J. A review of power output studies of olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *J Strength Cond Res* 7: 76–89, 1993.
15. Garhammer, J and Gregor, R. Propulsion forces as a function of intensity for weightlifting and vertical jumping. *J Strength Cond Res* 6: 129–134, 1992.
16. Garhammer, J and Takano, B. Training for weightlifting. *Strength and Power in Sport* 11: 357–369, 1992.
17. Haines, T, McBride, JM, Skinner, J, Woodall, M, Larkin, TR, Kirby, TJ, and Dayne, AM. Effect of load on bar, body and system power output in the power clean. *J Strength Cond Res* 24: 1, 2010.
18. Hori, N, Newton, R, Nosaka, K, and Stone, M. Weightlifting exercises enhance athletic performance that requires high- load speed strength. *Strength Cond J* 27: 50–55, 2005.
19. Hori, N, Newton, RU, Andrews, WA, Kawamori, N, McGuigan, MR, and Nosaka, K. Comparison of four different methods to measure power output during the hang power clean and the weighted jump squat. *J Strength Cond Res* 21: 314–320, 2007.
20. Hori, N, Newton, RU, Nosaka, K, and McGuigan, MR. Comparison of different methods of determining power output in weightlifting exercises. *Strength Cond J* 28: 34–40, 2006.
21. Janz, J and Malone, M. Training explosiveness: Weightlifting and beyond. *Strength Cond J* 30: 14–22, 2008.
22. Kawamori, N, Crum, AJ, Blumert, PA, Kulik, JR, Childers, JT, Wood, JA, Stone, MH, and Haff, GG. Influence of different relative intensities on power output during the hang power clean: Identification of the optimal load. *J Strength Cond Res* 19: 698–708, 2005.
23. Kawamori, N and Haff, GG. The optimal training load for the development of muscular power. *J Strength Cond Res* 18: 675–684, 2004.
24. Kawamori, N, Rossi, SJ, Justice, BD, Haff, EE, Pistilli, EE, O'Bryant, HS, Stone, MH, and Haff, GG. Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *J Strength Cond Res* 20: 483–491, 2006.
25. Kilduff, LP, Bevan, H, Owen, N, Kingsley, MI, Bunce, P, Bennett, M, and Cunningham, D. Optimal loading for peak power output during the hang power clean in professional rugby players. *Int J Sports Physiol Perform* 2: 260–269, 2007.
26. Lake, JP, Mundy, PD, and Comfort, P. Power and impulse applied during push press exercise. *J Strength Cond Res* 28: 2552–2559, 2014.
27. McBride, JM, Haines, TL, and Kirby, TJ. Effect of loading on peak power of the bar, body, and system during power cleans, squats, and jump squats. *J Sports Sci* 29: 1215–1221, 2011.
28. McBride, JM, Triplett-McBride, T, Davie, A, and Newton, RU. The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed. *J Strength Cond Res* 16: 75–82, 2002.
29. Sato, K, Smith, SL, and Sands, WA. Validation of an accelerometer for measuring sport performance. *J Strength Cond Res* 23: 341–347, 2009.
30. Sinclair, R. Normalizing the performance of athletes in olympic weightlifting. *Can J Appl Sport Sci* 10: 94–98, 1985.
31. Stone, MH. Position statement: Explosive exercise and training. *Strength Cond J* 15: 7–15, 1993.
32. Stone, MH, O'Bryant, HS, Mccoy, L, Coglianese, R, Lehmkuhl, M, and Schilling, B. Power and maximum strength relationships during performance of dynamic and static weighted jumps. *J Strength Cond Res* 17: 140–147, 2003.
33. Stone, MH, Pierce, KC, Sands, WA, and Stone, ME. Weightlifting: A brief overview. *Strength Cond J* 28: 50–66, 2006.
34. Suchomel, TJ, Comfort, P, and Stone, MH. Weightlifting pulling derivatives: Rationale for implementation and application. *Sports Med* 45: 1–17, 2015.

35. Thompson, CJ and Bemben, MG. Reliability and comparability of the accelerometer as a measure of muscular power. *Med Sci Sports Exerc* 31: 897–902, 1999.

36. Weir, JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 19: 231–240, 2005.

37. Winter, EM, Abt, G, Brookes, FBC, Challis, JH, Fowler, NE, Knudson, DV, Knuttgen, HG, Kraemer, WJ, Lane, AM, Mechelen, WV, Morton, RH, Newton, RU, Williams, C, and Yeadon, MR. Misuse of "power" and other mechanical terms in sport and exercise science research. *J Strength Cond Res* 30: 292–300, 2016.

Artículo III.

OPTIMAL LOAD AND POWER SPECTRUM DURING SNATCH AND CLEAN: DIFFERENCES BETWEEN INTERNATIONAL AND NATIONAL WEIGHTLIFTERS.

Resumen Artículo III.

OPTIMAL LOAD AND POWER SPECTRUM DURING SNATCH AND CLEAN: DIFFERENCES BETWEEN INTERNATIONAL AND NATIONAL WEIGHTLIFTERS.

CARGA ÓPTIMA Y ESPECTRO ÓPTIMO DE CARGAS EN LOS EJERCICIOS DE ARRANCADA Y CARGADA: DIFERENCIAS ENTRE HALTERÓFILOS DE NIVEL INTERNACIONAL Y DE NIVEL NACIONAL.

Objetivo/s.

El propósito de esta investigación fue determinar la carga óptima y el espectro óptimo de cargas requerido para alcanzar la máxima potencia mecánica en los ejercidos de arrancada y cargada con levantadores de nivel internacional y levantadores competitivos de nivel nacional.

Metodología.

Sujetos

Veintidós experimentados halterófilos hombres participaron en el presente estudio. La muestra se dividió en dos grupos de acuerdo con el nivel de rendimiento presentado por los levantadores. El grupo 1 estaba formado por once halterófilos de nivel competitivo internacional (dos húngaros, cuatro españoles y cinco griegos). Todos ellos eran o habían sido miembros de sus respectivas selecciones nacionales en el momento del estudio o bien en la temporada precedente, habiendo participando en alguna de las siguientes competiciones: Campeonatos de Europa, Campeonatos del Mundo y Juegos Olímpicos. Entre los levantadores que formaban este grupo había seis medallistas en Campeonatos de Europa, un medallista en Campeonato del Mundo y tres poseedores de récords nacionales en la actualidad. El grupo 2 estaba formado por levantadores de nivel competitivo nacional, siendo ocho de ellos medallistas en sus respectivas categorías de peso corporal en alguno de los Campeonatos de España de Halterofilia 2015 o 2016 o en ambos. De acuerdo con su mejor rendimiento deportivo el coeficiente Sinclair medio acreditado por los integrantes del grupo 1 en el momento de participar en el estudio fue de 395.69 ± 18.86 puntos mientras que para los integrantes del grupo 2 fue de 304.44 ± 27.07 puntos.

Procedimiento

Se realizaron dos sesiones de evaluación para cada uno de los sujetos. En la primera de ellas se determinó el 1RM de los sujetos en los ejercicios de arrancada y cargada. Y en la segunda sesión se realizó un test incremental de cargas progresivas para evaluar la potencia máxima generada a través de un espectro comprendido entre el 30 y el 90% (con incrementos del 10%) del 1RM previamente establecido para ambos ejercicios.

Resultados.

El grupo de levantadores de nivel internacional alcanzó la carga óptima para obtener la máxima potencia mecánica, con en el 90% del 1RM en el ejercicio de arrancada y cargada, mientras que el grupo de nivel nacional alcanzó la carga óptima con el 70% del 1RM en la arrancada y el 90% del 1RM en la cargada. En cuanto al espectro óptimo de cargas, el grupo de levantadores de nivel internacional localizó dicho espectro entre el 80% y el 90% del 1RM en la arrancada mientras que, en la cargada, este no fue localizado entre ninguna de las cargas evaluadas, existiendo por tanto diferencias significativas entre la carga óptima (90% del 1RM) y todo el espectro de cargas estudiado (30%-80% del 1RM). Por su parte, en el grupo de levantadores de nivel nacional, el espectro óptimo de cargas se situó entre el 70% y el 90% del 1RM para el ejercicio de arrancada y entre el 50% y el 90% del 1RM para el ejercicio de cargada.

Conclusiones.

Los resultados de este estudio revelaron la importancia que tiene la selección adecuada de la intensidad relativa (expresada como porcentaje del 1RM) sobre la producción de potencia durante los ejercicios de arrancada y cargada dependiendo del nivel deportivo de los levantadores. El presente trabajo mostró que tanto la carga óptima como el espectro óptimo de cargas difieren según el nivel de rendimiento de los halterófilos. Los levantadores de nivel internacional localizaron su carga óptima en el 90% del 1RM tanto en la arrancada como en la cargada, focalizando el espectro óptimo de cargas en la parte alta de curva carga-potencia (entre el 80% y el 90 del 1RM para la arrancada). Por su parte, los halterófilos de menor nivel (nivel nacional) localizaron su carga óptima con el 70% del 1RM en la arrancada, ubicando el espectro óptimo de cargas para este ejercicio entre el 70% y el 90% del 1RM, mientras que, en el ejercicio de cargada, la carga óptima fue alcanzada con el 90% del 1RM, aunque el espectro óptimo de cargas estaba comprendido entre el 50% y el 90% del 1RM. A la luz de los resultados obtenidos, parece lógico que los levantadores de menor nivel competitivo puedan utilizar un espectro de cargas más amplio a la hora de programar entrenamientos orientados a la mejora de la producción de potencia con los ejercicios de arrancada y cargada. Por otra parte, en el caso de levantadores de nivel internacional, estos deben focalizar el trabajo sobre la parte alta de la curva carga-potencia cuando su objetivo sea mejorar la producción de potencia.

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Optimal load and power spectrum during snatch and clean: differences between international and national weightlifters

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ABSTRACT

The aim of this study was to determine the optimal load (Pmax load) and optimal power spectrum (OPS) to achieve maximum power output (Pmax) during the snatch and clean with international weightlifters (IW) and national competitive weightlifters (NW). Twenty-two male weightlifters participated in two testing sessions. The first session involved performing one-repetition maximums (1RM) in the snatch and clean and second session assessed a power test across a spectrum of loads (30–90%) of each subject's 1RM in the predetermined exercises tested. Relative load had a significant effect on peak power, with Pmax load being obtained with 90% of 1RM for snatch and clean in the IW and 70 and 90% of 1RM for snatch and clean, respectively, in the NW. OPS was located between 80 and 90% for snatch and no OPS was found for the clean exercise in IW. In the NW, OPS was located between 70% up to 90% and 50% up to 90% in the snatch and clean, respectively. It may be advantageous to know the Pmax load and OPS in the snatch and clean when training to maximise power of weightlifters of different sport performance.

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KEYWORDS
Weightlifting; power; Pmax load; snatch; clean

1. Introduction

Power has been defined as the amount of work produced per unit of time (Hori, Newton, Nosaka, & Stone, 2005; Kawamori & Haff, 2004; Stone, Pierce, Sands, & Stone, 2006; Stone et al., 2003). During any exercise, Pmax is achieved through an optimal relationship between work and time (power = work/time). Weightlifting movements are known to elicit the greatest amount of power output of all resistance exercises (Kawamori & Haff, 2004; Suchomel, Comfort, & Stone, 2015), achieving these values during the second part of pull phase of the movement (Cormie, Mccaulley, Triplett, & Mcbride, 2007; Hori et al., 2005; Stone, 1993; Suchomel, Comfort, et al. 2015). Thus, the second pull of snatch and clean is known to elicit the greatest amount of power output of all resistance exercises (Cormie et al., 2007; Garhammer, 1993; Stone, 1993; Suchomel, Comfort, et al., 2015), accordingly weightlifting exercises are one of the most effective ways to develop power output (Lake, Mundy, & Comfort, 2014).

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The optimal load (Pmax load) is the load that elicits maximal power production in a certain movement (Cormie, McGuigan, & Newton, 2011). From a practical point of view, Pmax load and similar loads with no significant differences between them (defined as the optimal power spectrum) (Castillo et al., 2012) are considered the most appropriate stimuli to improve the power developed in a specific technical gesture (McBride, Triplett-McBride, Davie, & Newton, 2002). The Pmax load in weightlifting movements have been reported to occur with higher loads (described as percentage of 1RM) than in traditional resistance exercises (Castillo et al., 2012; Kawamori & Haff, 2004; McBride, Haines, & Kirby, 2011; Nacleiro, 2006; Suchomel, Beckham, & Wright, 2015; Suchomel, Comfort, et al., 2015). Because the Pmax attained varies with different relative loads (Kawamori & Haff, 2004), it is crucial that the load-power relationships of the snatch and clean should be examined in order to establish training recommendations for the use of these exercises.

Weightlifting success depends on how much weight the athlete can lift (1RM) and not on how much power the athlete can produce, however the importance of power production has been reported as a key factor in weightlifting. In that sense, Stone et al. (2006) claimed that power production is the most significant factor in determining success in weightlifting and likewise Hori et al. (2005) indicated that the success in weightlifting depends on the power applied to the barbell against high loads (high-load speed strength). According to previous studies (Garhammer, 1993; Stone, 1993; Stone et al., 2006), during weightlifting Pmax load is achieved with high loads, therefore, Pmax load is a key factor to achieve success during these types of exercises.

Some researchers have attempted to determine the percentage of 1RM that elicits maximal power output in some weightlifting movements but there is no uniform agreement between them (Comfort, Fletcher, & McMahon, 2012; Cormie et al., 2007; Kawamori & Haff, 2004; Suchomel, Beckham, et al., 2015). In that sense, it appears that the Pmax load is determined by multiple factors like the nature of the exercise and training status within a yearly training cycle (Kawamori & Haff, 2004), experience of the athlete, or strength background (Baker, Nance, & Moore, 2001a, 2001b; Nacleiro, 2006). These controversies with regard to the Pmax load could be partly explained by numerous methodological differences carried out in the studies such as the reporting of peak power vs. mean power development, equipment used (Cormie et al., 2007), inclusion of the barbell or entire system mass in calculation (McBride et al., 2011), strength level between athletes (Baker et al., 2001a, 2001b; Nacleiro, 2006) and technical proficiency (Nacleiro, 2006).

To date, the percentage of 1RM that yields maximal power output for the snatch is limited to one previously published study (Pennington, Laubach, de Marco, & Linderman, 2010). In addition, the other weightlifting movements studied have been usually variations of the classical weightlifting competition exercises: power clean (Comfort et al., 2012; Cormie et al., 2007; Kawamori et al., 2006; McBride et al., 2011; Pennington et al., 2010), hang power clean (Hori et al., 2007; Kilduff et al., 2007; Suchomel, Beckham, & Wright, 2014), hang high pull (Suchomel, Beckham, et al., 2015), push press (Lake et al. (2014) and back jerk (Flores, Sedano, & Redondo, 2017) in respect of which the subjects usually did not have technical mastery practising them. To our knowledge, no previous investigations have compared the Pmax load in the snatch and clean between weightlifters of different performance profiles. Hence, the aim of this investigation was to find Pmax load and optimal power spectrum (OPS) required to elicit Pmax during the snatch and clean in two groups; international weightlifters (IW) and national weightlifters (NW), comparing the differences between exercises and groups of performance. In line with research findings (Flores et al., 2017; Garhammer, 1993; Stone, 1993; Stone et al., 2006), it was hypothesised that there would be a strong relationship between these two exercises maximising Pmax towards the heavier end of the load-power curve (70–90% of 1RM) with the highest Pmax being achieved in the IW. Consequently, it would be useful to determine the Pmax load to optimise Pmax during the snatch and clean movements with different levels of performance in order to establish power training recommendations for weightlifters.

2. Methods

2.1. Subjects

Twenty-two male weightlifters participated in the study. The sample was divided in two groups taking into account the sports performance. The group 1; international weightlifters group (IW) was formed by 11 elite weightlifters (2 Hungarian, 4 Spanish and 5 Greeks), all of them have been members of their respective senior national teams on the current, or at least, the season before, participating in World or European Championship or Olympic Games (6 European Championship medallists, 1 World Championship medallist and 3 national current record holders). The group 2; national competitive weightlifters group (NW), was formed by 11 weightlifters (8 medallists at their National Championships in 2015 and/or 2016 seasons). On the basis of their best weightlifting performance in competition, their Sinclair coefficient was 395.69 ± 18.86 by the IW and 304.44 ± 27.07 by the NW (Sinclair, 1985). The descriptive characteristics of the weightlifters are shown in Table 1. Prior to participation in the study, all subjects read and signed an informed consent in accordance with guidelines set by the Human Subjects Review Committee at University of Salamanca. The study conformed to the principles of the World Medical Association's Declaration of Helsinki.

2.2. Procedures

Two test sessions were carried out in the weightlifters' usual training environment to record 1RM and barbell acceleration, which was subsequently used to calculate power. Before the

Table 1. Descriptive data for participant's characteristics (*M* ± SD).

Characteristics	IW (*n* = 11)	NW (*n* = 11)
Age (years)	24.18 ± 5.70	25.09 ± 6.10
Height (m)	175.18 ± 8.13	175.72 ± 4.80
Body mass (kg)	88.67 ± 27.49	82.67 ± 14.08
Sinclair coefficient	395.69 ± 18.86	304.44 ± 27.07
Weightlifting experience (years)	13.46 ± 8.20	13.27 ± 6.60
1RM (snatch/clean) (kg)		
Subject 1	(115/145)	(90/120)
Subject 2	(156/170)	(130/150)
Subject 3	(148/185)	(110/140)
Subject 4	(100/130)	(90/120)
Subject 5	(125/155)	(100/120)
Subject 6	(130/200)	(100/115)
Subject 7	(155/188)	(110/130)
Subject 8	(140/170)	(110/132)
Subject 9	(100/120)	(115/135)
Subject 10	(120/150)	(122/146)
Subject 11	(160/190)	(102/115)

start of each test session, participants went through a standardised warm-up composed of 5 min of light-intensity cycling followed by 5 min of a series of dynamic stretches. After this general warm-up, participants engaged in 10 min of specific warm-up involving the actual movement of the snatch and clean. In both sessions the order of the exercises assessed was snatch followed by clean, and a 10-min rest was allowed between exercises. This recovery period is similar to that applied in weightlifting competitions between the snatch and the clean and jerk.

2.2.1. 1RM testing

The subjects' 1RM was obtained for the snatch and clean following the standardised protocol presented by Baechle and Earle (Baechle & Earle, 2008). The weightlifters had previously performed 1RM tests numerous times and therefore were well accustomed to the procedures for the test.

2.2.2. Power testing

2–4 days after their 1RM was established, a power test session was performed. After the warm-up exercise sets, subjects carried out a maximum effort repetition with each load, which was systematically increased to 30, 40, 50, 60, 70, 80 and 90% of the subject's predetermined 1RM. The recovery period between loads was determined by the athlete, but was in all cases between 3 and 5 min. A 3-axis accelerometer (PS-2136A, PASCO, Roseville, CA) operating at 100 Hz and a Bluetooth wireless device (Airlink 2 PS-2010, PASCO, Roseville, CA) were used in the power testing. Previous studies showed that 100 Hz is an appropriate sampling rate to record weightlifting exercises (Sato, Smith, & Sands, 2009). The reliability of the results offered by these tests with the current measuring protocol was previously validated by Flores, Sedano, de Benito, and Redondo (2016). This device was chosen for its easy portability in the weights room and minimal disturbance of the flow of the lifting sessions without compromising the weightlifter's technique in data collection (Sato et al., 2009). The accelerometer was placed on the bar according to the procedures explained by Flores et al. (2016) (Figure 1).

The data were processed thereafter, using Pasco Capstone software (Version 1.1.5, Pasco Scientific PASCO, Roseville, CA) and barbell peak power outputs (highest instantaneous value during each lift) were calculated from acceleration according to the methodology previously explained by Thompson and Bemben (Thompson & Bemben, 1999). According to Flores et al. (2016) data analysis included only the vertical acceleration attained by the barbell that was lifted, but only up to the finish of pull phase of the exercises assessed. It should be noted that the lifter's body weight was not included in the calculations, so that the power calculations recorded the work done against the bar by the lifter. The exclusion of the body weight in the calculations gives more important information about weightlifting performance because, although the lifters have to accelerate their body mass throughout the lifts, the centre of gravity of the barbell and the system (bar plus body mass) move independently of one another and the success of weightlifting depends on the power applied to the barbell regardless of the lifter's body mass (Hori et al., 2007; McBride et al., 2011). Moreover, according to McBride et al. (2011) peak power is very similar for the bar, body, and system (bar plus body mass) thus, although the methodology used would have few, if any, training implications (McBride et al., 2011), the methodology chosen to determine the Pmax load should depend on the characteristics of the sport itself. In that sense, to measure

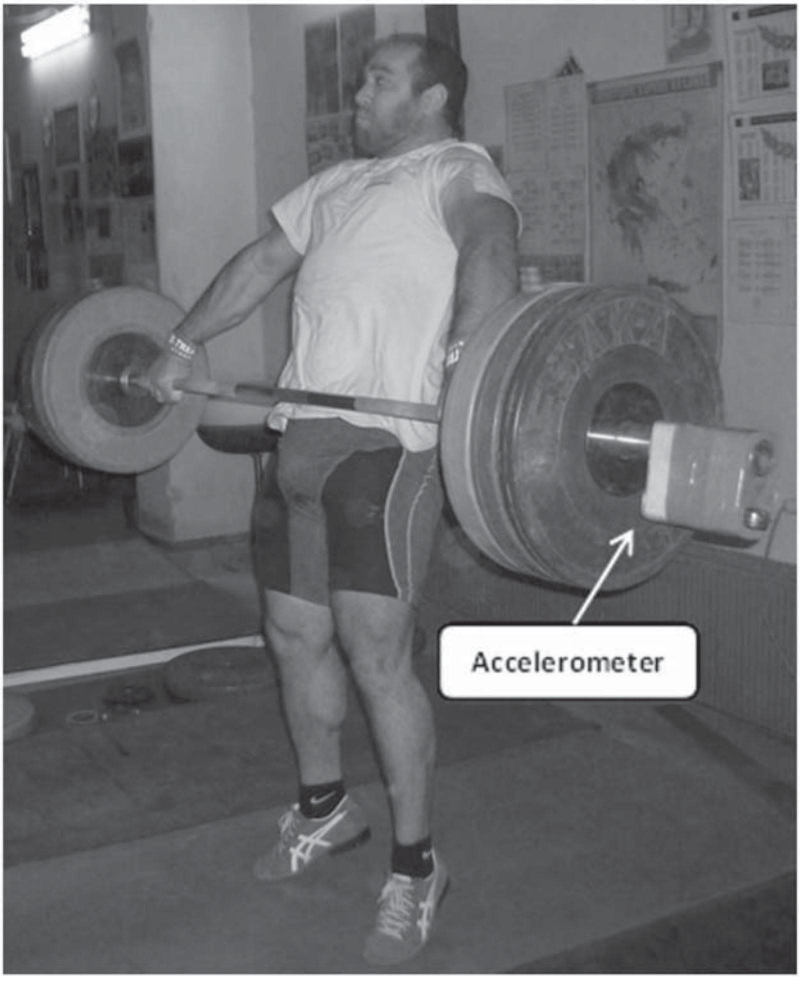

Figure 1. Weightlifter performs a lift with the accelerometer fixed to the bar according to the established protocol by Flores et al. (2016).

specifically the power applied to the barbell may be the primary outcome measure when assessing sports involving the movement of an external object (i.e. weightlifting) (Hori et al., 2007; McBride et al., 2011).

Participants were allowed to use the hook grip, chalk, weightlifting belt and weightlifting shoes, but were not allowed to use weightlifting straps. Strong verbal encouragement was given to all participants to motivate them to perform each lift as maximally and as powerfully as possible.

3. Statistical analyses

Normality of distribution was tested by means of the Kolmogorov–Smirnov test. Standard statistical methods were used to calculate the mean ± *s*. Repeated measures two-way analysis of variance (ANOVA) (factors: load and lift) and two-way ANOVA with repeated measurements (factors: load and group) were used to analyse peak power with loads of 30–90% and, power-related effects and the differences between level groups, respectively. When a significant *F* value was achieved by means of Wilks' lambda, Scheffe's *post hoc* procedures were performed to locate the pairwise differences. The Bonferroni correction for multiple comparisons was applied. Additionally, Cohen's *d* (Cohen, 1988) effect sizes and 95% confidence intervals were estimated for each variable. A significance level of .05 was adopted for all statistical tests that were performed in the program SPSS version 18.0 (Chicago, IL, USA).

4. Results

The Kolmogorov–Smirnov test shown that all variables were distributed normally ($p > .05$).

4.1. Snatch and clean: comparison between level groups

The results of snatch and clean comparison between both levels of performance are presented in Table 2. In both exercises and all loads assessed IW shown higher values of peak power than NW. Significant differences "load × group" ($p < .01$, $d = .44$) were exhibited between IW and NW in the snatch above the 50% of 1RM (Figure 2). ANOVA revealed significant "load × group" interaction effects for clean (Figure 2) above the 70% of 1RM ($p < .05$, $d = .15$).

Table 2. Descriptive data for power for snatch and clean for each test occasion and level group.[a]

		Peak power (W)		95% Confidence interval	
Load (% 1RM)	Group	Snatch	Clean	Lower bound	Upper Bound
30	IW	2053.87 ± 413.99†		1735.65	2372.09
			2031.66 ± 501.99†	1694.42	2368.90
	NW	1843.82 ± 575.49†		1401.46	2286.18
			1670.35 ± 407.33†	1396.70	1944.00
40	IW	2521.23 ± 456.11†		2170.63	2871.83
			2433.65 ± 643.04†	2001.65	2865.65
	NW	2394.83 ± 510.66†		2002.31	2787.36
			2127.25 ± 414.63†	1848.70	2405.81
50	IW	2859.22 ± 288.53†		2637.44	3081.01
			2911.69 ± 682.32†	2453.30	3370.08
	NW	2749.73 ± 611.29†		2279.85	3219.61
			2587.93 ± 615.58	2174.38	3001.49
60	IW	3479.47 ± 774.80†		2883.91	4075.04
			3169.12 ± 640.57†	2738.78	3599.46
	NW	2874.55 ± 325.27†		2624.52	3124.57
			2667.97 ± 470.15	2352.12	2983.82
70	IW	3603.56 ± 770.24†		3011.50	4195.63
			3205.25 ± 662.58†	2760.12	3650.38
	NW	3084.40 ± 430.32		2753.63	3415.18
			2885.18 ± 479.20	2563.25	3207.11
80	IW	3961.87 ± 997.14		3195.40	4728.33
			3521.65 ± 739.57†	3024.81	4018.50
	NW	3075.28 ± 485.58		2702.03	3448.53
			2833.56 ± 491.04	2503.68	3163.45
90	IW	4185.86 ± 1061.79		3369.70	5002.03
			3753.08 ± 843.39	3186.48	4319.68
	NW	3014.20 ± 383.54		2719.38	3309.01
			2919.74 ± 531.14	2562.91	3276.56

[a]Values are given as mean ± SD.
†Significantly different ($p < .001$) from Pmax load.

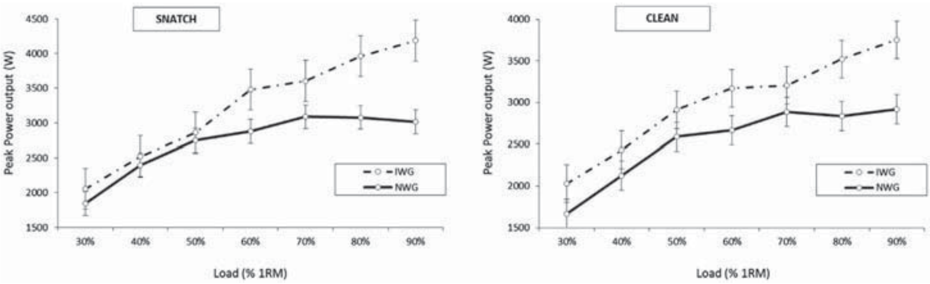

Figure 2. Peak power output at loads of 30–90% of one repetition maximun (1RM) during snatch and clean for IW and NW.
Note: Significant differences between IWF and NWF for 80 and 90% in snatch and clean.

4.2. The effect of load on the international weightlifters group

For snatch, significant differences “load × lift” ($p < .01$, $d = .97$) were exhibited between loads of 30–90% and Scheffe’s *post hoc* tests found differences between 90% (Pmax load) and 30% ($p < .01$, $d = 2.54$), 40% ($p < .01$, $d = 1.88$), 50% ($p < .01$, $d = 1.64$), 60% ($p < .01$, $d = .77$), and 70% ($p < .01$, $d = .59$). For clean, ANOVA revealed significant “load × lift” ($p < .01$, $d = .97$) interaction effects and Scheffe’s *post hoc* tests located the differences between 90% and 30% ($p < .01$, $d = 2.48$), 40% ($p < .01$, $d = 1.76$), 50% ($p < .01$, $d = 1.09$), 60% ($p < .05$, $d = .78$), 70% ($p < .01$, $d = .72$) and 80% ($p < .05$, $d = .29$).

Snatch and clean peak power increased from 30% up to 90% of 1RM achieving the highest power values with 90% of 1RM in both exercises. Table 2 shows the peak power obtained for IW across all loading conditions for the snatch and clean. The Pmax for snatch was 4185.86 ± 724.45 W and 3753.08 ± 557.56 W for clean exercise.

Snatch and clean Pmax was observed with the 90% of 1RM for IW. In the snatch, no significant differences were found between 90% (Pmax load) and 80% of 1RM identifying this interval as the OPS for this exercise and group (Figure 3). In the clean significant differences were observed between the 90% (Pmax load) of 1RM and all spectrum of loads assessed (Figure 3).

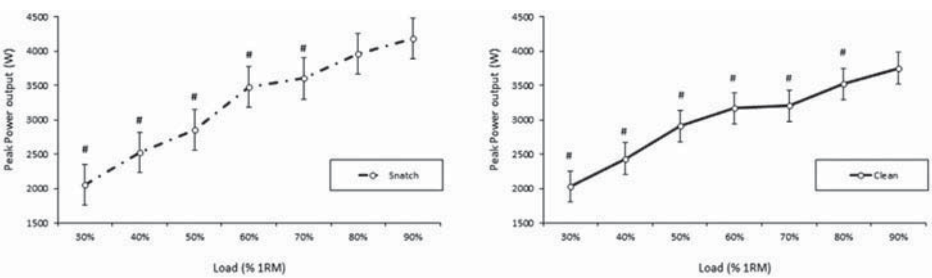

Figure 3. Peak power output at loads of 30–90% of one repetition maximun (1RM) during snatch and clean for IW.
Note: # = significant diferent from Pmax load (90% in both exercises).

4.3. The effect of load on the national weightlifters group

For snatch, ANOVA reflected significant "load × lift" interaction effects ($p < .01$, $d = .98$) and Scheffe's *post hoc* tests located the differences between 70% and 30% ($p < .01$, $d = 2.44$), 40% ($p < .01$, $d = 1.56$), 50% ($p < .05$, $d = .68$) and 60% ($p < .05$, $d = .65$) and for clean the significant differences ($p < .01$, $d = .98$) and Scheffe's *post hoc* tests only registered differences between 90% and 30% ($p < .01$, $d = 2.48$), 40% ($p < .01$, $d = 1.40$) and 50% ($p < .05$, $d = .49$).

Snatch and clean peak power increased from 30% up to 70% of 1RM in both exercises. Table 2 shows the peak power obtained for NW across all loading conditions for the snatch and clean. The Pmax for the snatch was 3084.40 ± 421.52 W achieved with 70% of 1RM and the Pmax for the clean was 2919.74 ± 429.91 W achieved with 90% of 1RM.

For the NW snatch and clean Pmax was observed with the 70 and 90% of 1RM, respectively. In the snatch, no significant differences were found between 70%, (Pmax load) 80% and 90% of 1RM identifying this interval (70–90%) as the OPS for this exercise and group (Figure 4). In the clean no significant differences were observed between 90% (Pmax load) and 80, 70, 60 and 50% of 1RM identifying this interval (50–90%) as the OPS for this exercise and group (Figure 4).

5. Discussion

The purpose of this research was to determine the optimal load (Pmax load) and OPS in the snatch and clean exercises comparing the differences between international weightlifters (IW) and national competitive weightlifters (NW). The Pmax load was observed with 90% of 1RM for snatch and clean in the IW and 70 and 90% of 1RM for snatch and clean, respectively in the NW. In the IW, OPS occurred between 80% and 90% of 1RM in the snatch and no OPS was found for the clean exercise. In NW, OPS was found between 70 and 90% of 1RM in snatch and between 50 and 90% for clean exercise. According to our initial hypothesis, the findings of this study support the importance of the load percentage to achieve Pmax load being this percentage specific of each exercise. In addition, Pmax generated during the snatch and clean by IW were higher than generated by NW and with higher percentages of 1RM.

Training in weightlifting focuses on generating high levels of muscular power during the lift as well as to transfer that power to the bar in a short period of time (Campos, Poletaev,

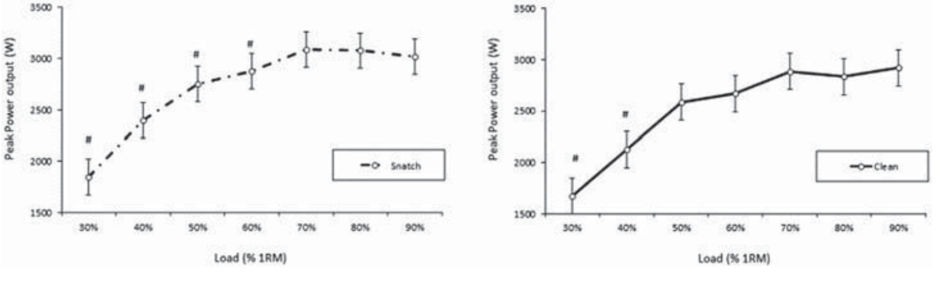

Figure 4. Peak power output at loads of 30–90% of one repetition maximun (1RM) during snatch and clean for NW.
Note: # = significantly different from Pmax load (70% for snatch and 90% for clean).

Cuesta, Pablos, & Carratala, 2006). During weightlifting exercises, such as snatch, clean, jerk, and variations of these movements, the centre of gravity of the barbell and the system (bar plus body mass) do not move in parallel (Cormie et al., 2007; McBride et al., 2011). According to this, one of the weightlifter's objectives is moving an external object, the barbell mass, as fast as possible because the success of weightlifting depends on the power applied to the barbell (Hori et al., 2007; McBride et al., 2011). Taking into account only the power applied to the barbell, Pmax load during weightlifting exercises and their derivatives has been reported ranging from 70 to 90% of 1RM (Flores et al., 2017; Haines et al., 2010; Nacleiro, 2006; Pennington et al., 2010).

The present study confirm that in weightlifters of international and national competitive levels, the Pmax load during snatch and clean is achieved with higher percentages of 1RM than Pmax load reported previously during traditional resistance exercises (Castillo et al., 2012; Kawamori & Haff, 2004; McBride et al., 2011; Nacleiro, 2006; Suchomel, Beckham, et al., 2015; Suchomel, Comfort, et al., 2015). In the current work, IW achieved the Pmax load with 90% of 1RM during the snatch and clean and the OPS was located at the top of power load curve studied during the snatch. On the other hand, NW shown wider OPS (from 70% up to 90% for the snatch and from 50% up to 90% for the clean) being these results in line with other studies where no statistically significant differences were reported between the Pmax load and loads ranging from 60 to 80% of 1RM, in power clean (Comfort et al., 2012) or from 50 to 90% of 1RM, in power clean and hang power clean (Cormie et al., 2007; Kilduff et al., 2007). However, it is necessary to be aware of comparing the results of these investigations with the present study because different systems to take data, methodologies and forms to calculate power (inverse and forward dynamics) have been used.

The results of the current study to achieve Pmax load (90% of 1RM in snatch and clean for IW and clean for NW) was the same result reported by McBride et al. (2011) using power clean. In this regard the authors of the current study found the same percentage to reach Pmax load in a previous study carried out using the same measurement system and methodology during exercises of jerk and back jerk in a group of competitive weightlifters (Flores et al., 2017).

The high percentage of 1RM found in the present study to achieve Pmax load might be influenced by the strength profile of the subjects (international and national competitive weightlifters). Thus, it has been suggested that the level of experience and proficiency of the athletes could be expected to shift the percentage of maximum strength at which the highest power is produced either upward or downward (Kawamori & Haff, 2004; Nacleiro, 2006). In this way, the strength level of the athletes could be a confounding factor (Kilduff et al., 2007). For example, in line with the current study, Stone et al. (2003) found that in squat jumps weaker athletes produced the maximal power output at a lower relative load than did stronger. The same trend was reported by Kilduff et al. (2007) using hang power clean exercises with professional rugby players. However, there is no uniform agreement between researchers and contradictory results were reported by others authors (Baker et al., 2001a, 2001b), suggesting that stronger athletes used lower percentages of 1RM than weaker to maximise power output during jump squats and bench press throw. However, in order to compare the results of these studies it should be taken into account the different methodologies used, because the various results would be influenced by the type of methodology applied in each of them. In that sense, Kilduff et al. (2007) reported the peak power calculated through forward dynamics, Stone et al. (2003) reported the peak power calculated through inverse dynamics while, Baker et al. (2001a, 2001b) used inverse dynamics to report the average mechanical power.

The lower percentage to achieve Pmax load in the present study was found in the snatch for NW with 70% of 1RM. Although no statistical differences were revealed between 70% up to 90% of 1RM, this lower percentage to achieve Pmax load could be explained by the most difficult technique of snatch (Gourgoulis, Aggelousis, Mavromatis, & Garas, 2000; Nacleiro, 2006) and the lower sport level of NW.

The power data obtained at the present work are findings significantly lower than those previously reported by Stone (1993) and Garhammer (1993) (5600 W and almost 7000 W respectively). These discrepancies might be attributable to variations in the methodological procedures used (Hori et al., 2007; McBride et al., 2011; Stone, 1993), like how to collect and analyse power output, the sampling rate, the body mass of the athletes, the use of average power or peak power or the conditions for data collection. In the current study the body mass of the sample was 88.67 ± 27.49 kg for IW and 82.67 ± 14.08 kg for NW which is much less than the 100 kg and 125 kg of the lifters studied by Stone (1993) and Garhammer (1993), respectively. In addition, these previous works reported the average power through video analysis under competition conditions, while in the current study the evaluation of peak power was carried out in training conditions. Moreover, in the present study the horizontal component and the work performed by displacing the lifter's centre of mass were not taken into account. These differences could well be decisive in explaining the variability reported in the power values in these studies. On the other hand, the current findings are in line to the preceding results of Garhammer (1991) who identified the average power output generated during a snatch lift ranges from 1300 to 4000 W among elite male lifters, similar sample comparing to IW of the present work.

According to Garhammer (1993) horizontal component during weightlifting is usually small but not always negligible because some weightlifters generate large horizontal barbell accelerations at the beginning of the second pull during snatch and clean. During the current study the work performed horizontally displacing the barbell was rejected taking into account only the vertical component according with the methodology previously validated by Flores et al. (2016). According to Garhammer (1993), the horizontal work produced by a lifter of a light weight division represents a small component lesser than 5 % of the total work produced, being this component for heavy weight divisions around 10 % of the total work. During the current study the body mass of the sample was 88.67 ± 27.49 kg for IW and 82.67 ± 14.08 kg for NGW (Table 1). These values would be included within of middle body weight divisions in weightlifting and although according to Garhammer (1993) the weightlifters included in these categories would not generate maximum horizontal component values (around 10%), this fact should be kept in mind by the reader of this study. This neglect of the horizontal component of work during the current study should be taken into account to compare works where horizontal and vertical components have been studied together.

The results of the present study, taken together with the details given above, suggest that weightlifting movements and their variations require a heavier relative load to maximise power output in weightlifters. According to Lake et al. (2014) this might be explained by the fact that, although ballistic, load projection must be performed under control and within technical patterns, which may prevent achieving maximum power outputs with lighter loads. It is likely that this idea could explain why the weightlifters are unable to apply the maximum velocity possible to the bar with lighter loads. Thus, loads below 80% of 1RM analysed in the present work were probably not performed with maximal intent, as this would result in the participants performing power snatch or power clean and not snatch or clean. In that sense, González-Badillo (1991) claimed that a correct technical execution should allow lifting the 85% of 1RM of snatch or clean in power snatch or power clean, respectively, for good balanced weightlifters.

As hypothesised, the results of the current investigation demonstrate that elicited Pmax in IW is greater than in NW at all loads assessed, being these differences statistically significant at the top of the power load curve (Figure 2). This could be explained by the higher level of performance of IW, exhibiting a better ability to develop high power values with high percentages of loads where the technical mastery of movement is key to ensuring a successful lift (Gourgoulis et al., 2000).

The results of this study should be considered in light of a few limitations. Firstly, the peak power is referred only to the vertical component of the bar. Although according to Garhammer (1993) horizontal work is usually small for weightlifting, even negligible during the jerk, some weightlifters generate large horizontal accelerations at the beginning of the second pull for snatch or clean lift, which was not taken into account in this study. Secondly, due to the methods used to calculate power (inverse dynamics based on barbell displacement) the findings of this study are mainly applicable to sports where to move an external mass as fast as possible is the main goal (e.g. throwing or weightlifting) but it less applicable to other (e.g. sprinting or jumping) where power production against one's own body is crucial to achieve high performance (McBride et al., 2011). And finally, power against 100% of 1RM was not assessed so we cannot conclude definitely that 90% is the Pmax load. Future studies may identify roundly the Pmax load including the evaluation power with 100% of 1RM.

6. Conclusion

If the load control is essential to ensure the specificity of results and training adaptations (Jandacka & Uchytil, 2011), and Pmax loads are specific to each exercise (Soriano, Jiménez-Reyes, Rhea, & Marín, 2015), it is important for coaches to be aware of the Pmax load and OPS of the snatch and clean exercises according to the different performance of the athletes. Based on the outcomes of this investigation, it is recommended that international weightlifters use loads between 80 and 90% of 1RM in snatch and clean to improve their power output in these exercises. On the other hand, competitive weightlifters of national level could benefit from using lower loads in a wider spectrum of loads, 50–90% of 1RM in clean and 70–90% of 1RM in snatch when setting out training programmes to improve the power output.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Baechle, T. R., & Earle, R. W. (2008). *Essentials of strength training and conditioning*. Champaign, IL: Human Kinetics.

Baker, D., Nance, S., & Moore, M. (2001a). The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *Journal of Strength and Conditioning Research, 15*, 20–24.

Baker, D., Nance, S., & Moore, M. (2001b). The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *Journal of Strength and Conditioning Research, 15*, 92–97.

Campos, J., Poletaev, P., Cuesta, A., Pablos, C., & Carratala, V. (2006). Kinematical analysis of the snatch in elite male junior weightlifters of different weight categories. *Journal of Strength and Conditioning Research, 20*, 843–850.

Castillo, F., Valverde, T., Morales, A., Pérez-Guerra, A., De León, F., & García-Manso, J. (2012). Maximum power, optimal load and optimal power spectrum for power training in upper-body (bench press): A review. *Revista Andaluza de Medicina del Deporte, 5*, 18–27.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Comfort, P., Fletcher, C., & McMahon, J. J. (2012). Determination of optimal loading during the power clean, in collegiate athletes. *Journal of Strength and Conditioning Research, 26*, 2970–2974.

Cormie, P., Mccaulley, G. O., Triplett, N. T., & Mcbride, J. M. (2007). Optimal loading for maximal power output during lower-body resistance exercises. *Medicine and Science in Sports and Exercise, 39*(2), 340–349.

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power. *Sports Medicine, 41*, 17–38.

Flores, F. J., Sedano, S., de Benito, A. M., & Redondo, J. C. (2016). Validity and reliability of a 3-axis accelerometer for measuring weightlifting movements. *International Journal of Sports Science & Coaching, 11*, 872–879.

Flores, F. J., Sedano, S., & Redondo, J. C. (2017). Optimal load and power spectrum during jerk and back jerk in competitive weightlifters. *Journal of Strength and Conditioning Research, 31*, 809–816.

Garhammer, J. (1991). A comparison of maximal power outputs between elite male and female weightlifters in competition. *International Journal of Sport Biomechanics, 7*, 3–11.

Garhammer, J. (1993). A review of power output studies of olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *Journal of Strength and Conditioning Research, 7*, 76–89.

González-Badillo, J. J. (1991). *Halterofilia*. Madrid: Comité Olímpico Español.

Gourgoulis, V., Aggelousis, N., Mavromatis, G., & Garas, A. (2000). Three-dimensional kinematic analysis of the snatch of elite Greek weightlifters. *Journal of Sports Sciences, 18*, 643–652.

Haines, T., McBride, J. M., Skinner, J., Woodall, M., Larkin, T. R., Kirby, T. J., & Dayne, A. M. (2010). Effect of load on bar, body and system power output in the power clean. *Journal of Strength and Conditioning Research, 24*, 1.

Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., & Nosaka, K. (2007). Comparison of four different methods to measure power output during the hang power clean and the weighted jump squat. *Journal of Strength and Conditioning Research, 21*, 314–320.

Hori, N., Newton, R. U., Nosaka, K., & Stone, M. H. (2005). Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength & Conditioning Journal, 27*, 50–55.

Jandacka, D., & Uchytil, J. (2011). Optimal load maximizes the mean mechanical power output during upper extremity exercise in highly trained soccer players. *Journal of Strength and Conditioning Research, 25*, 2764–2772.

Kawamori, N., & Haff, G. G. (2004). The optimal training load for the development of muscular power. *Journal of Strength and Conditioning Research, 18*, 675–684.

Kawamori, N., Rossi, S. J., Justice, B. D., Haff, E. E., Pistilli, E. E., O'Bryant, H. S., … Haff, G. G. (2006). Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *Journal of Strength and Conditioning Research, 20*, 483–491.

Kilduff, L. P., Bevan, H., Owen, N., Kingsley, M. I., Bunce, P., Bennett, M., & Cunningham, D. (2007). Optimal loading for peak power output during the hang power clean in professional rugby players. *International Journal of Sports Physiology and Performance, 2*, 260–269.

Lake, J. P., Mundy, P. D., & Comfort, P. (2014). Power and impulse applied during push press exercise. *Journal of Strength and Conditioning Research, 28*, 2552–2559.

McBride, J. M., Haines, T. L., & Kirby, T. J. (2011). Effect of loading on peak power of the bar, body, and system during power cleans, squats, and jump squats. *Journal of Sports Sciences, 29*, 1215–1221.

McBride, J. M., Triplett-McBride, T., Davie, A., & Newton, R. U. (2002). The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed. *Journal of Strength and Conditioning Research, 16*, 75–82.

Nacleiro, F. (2006). *Análisis de la fuerza y la potencia mecánica producida en los ejercicios con resistencias en diferentes poblaciones de deportistas a lo largo de la temporada* [Analysis of the force and mechanical power produced in resistance exercises over a season with different athletes] (Master's thesis). University of León, León (Spain).

Pennington, J., Laubach, L., de Marco, G., & Linderman, J. (2010). Determining the optimal load for maximal power output for the power clean and snatch in collegiate male football players. *Journal of Exercise Physiology Online, 13*, 10–20.

Sato, K., Smith, S. L., & Sands, W. A. (2009). Validation of an accelerometer for measuring sport performance. *Journal of Strength and Conditioning Research, 23*, 341–347.

Sinclair, R. (1985). Normalizing the performance of athletes in olympic weightlifting. *Canadian Journal of Applied Sport Sciences, 10*, 94–98.

Soriano, M. A., Jiménez-Reyes, P., Rhea, M. R., & Marín, P. J. (2015). The optimal load for maximal power production during lower-body resistance exercises: A meta-analysis. *Sports Medicine, 45*, 1191–1205.

Stone, M. H. (1993). Position statement: Explosive exercise and training. *National Strength & Conditioning Association Journal, 15*, 7–15.

Stone, M. H., O'Bryant, H. S., Mccoy, L., Coglianese, R., Lehmkuhl, M., & Schilling, B. (2003). Power and maximum strength relationships during performance of dynamic and static weighted jumps. *Journal of Strength and Conditioning Research, 17*, 140–147.

Stone, M. H., Pierce, K. C., Sands, W. A., & Stone, M. E. (2006). Weightlifting: A brief overview. *Strength & Conditioning Journal, 28*, 50–66.

Suchomel, T. J., Beckham, G. K., & Wright, G. A. (2014). The impact of load on lower body performance variables during the hang power clean. *Sports Biomechanics, 13*, 87–95.

Suchomel, T. J., Beckham, G. K., & Wright, G. A. (2015). Effect of various loads on the force-time characteristics of the hang high pull. *Journal of Strength and Conditioning Research, 29*, 1295–1301.

Suchomel, T. J., Comfort, P., & Stone, M. H. (2015). Weightlifting pulling derivatives: Rationale for implementation and application. *Sports Medicine, 45*, 823–839.

Thompson, C. J., & Bemben, M. G. (1999). Reliability and comparability of the accelerometer as a measure of muscular power. *Medicine and Science in Sports and Exercise, 31*, 897–902.

Artículo IV.

POWER-LOAD CURVES IN AN ELITE WEIGHTLIFTER. A CASE STUDY.

Resumen Artículo IV.

POWER-LOAD CURVES IN AN ELITE WEIGHTLIFTER. A CASE STUDY.

CURVAS DE CARGA-POTENCIA EN UN HALTERÓFILO DE ÉLITE. ESTUDIO DE CASO.

Objetivo/s.

El propósito de este estudio fue analizar y comparar las curvas de carga-potencia en los ejercicios de arrancada, cargada, yerk tras-nuca y yerk, así como determinar la carga óptima para alcanzar la máxima potencia mecánica para cada uno de estos ejercicios en un halterófilo de élite español.

Metodología.

Sujeto

El participante de este estudio fue un halterófilo de élite, actualmente récord de España de dos tiempos (148 kg) y total olímpico (265 kg) y ex récord nacional de arrancada (119 kg) todo ello en la categoría de peso corporal de 62 kg. De acuerdo a su mejor rendimiento en competición, el atleta estudiado tiene acreditado un coeficiente Sinclair de 387.76 puntos.

Procedimiento

En el presente trabajo se realizaron cuatro sesiones de evaluación. En las sesiones primera y tercera se evaluó el 1RM del sujeto en los ejercicios de arrancada y cargada (sesión uno) y yerk tras-nuca y yerk (sesión tres). En la segunda sesión (arrancada y cargada) y en la cuarta (yerk tras-nuca y yerk) se realizó un test incremental de cargas progresivas para evaluar la potencia máxima generada a través de un espectro comprendido entre el 30 y el 100% (con incrementos del 10%) de los 1RM previamente establecidos.

Material

Durante las sesiones de evaluación segunda y cuarta (test incrementales de cargas), para la recolección de los datos se utilizó un acelerómetro de 3 ejes PS- 2136A (PASCO Scientific, Roseville, CA, USA) conectado vía Bluetooth a un ordenador portátil y operando a 100Hz. La validez y fiabilidad del dispositivo y protocolo de medición fue publicada previamente en el primero de los artículos de esta tesis (artículo I).

Resultados.

El análisis de las curvas de carga-potencia realizado mostró como el pico de potencia generado por el levantador incrementó de forma progresiva desde el 30 hasta el 90% del 1RM en los ejercicios de arrancada, cargada y yerk, y decaía marcadamente con la última de las cargas evaluadas, el 100% del 1RM del sujeto. En el ejercicio yerk tras-nuca, la curva de carga-potencia mostró dos picos, uno con el 60% del 1RM y otro con el 90% del 1RM, mostrando, como en el resto de los ejercicios, una caída marcada de la potencia generada con el 100% del 1RM. Durante los cuatro ejercicios evaluados, la carga óptima fue alcanzada con el 90% del 1RM desarrollando el mayor nivel en términos absolutos de potencia con el yerk tras-nuca, seguido de la arrancada, yerk y finalmente la cargada.

Conclusiones.

Hasta el momento nadie ha intentado describir las curvas de carga-potencia incluyendo el 100% de la 1RM en los ejercicios de arrancada, cargada, yerk tras-nuca y yerk con un halterófilo de élite. Sin embargo, es necesario que existan más estudios en esta línea ya que el determinar cuál es la carga óptima para alcanzar la máxima potencia mecánica en halterofilia es una importante fuente de información de cara a incrementar el rendimiento en este deporte. Sobre la base de los resultados de esta investigación, se podría concluir que el levantador estudiado alcanzó la carga óptima durante los ejercicios de arrancada, cargada, yerk tras-nuca y yerk con una carga del 90% del 1RM, siendo este porcentaje de carga, para este levantador, el estímulo más adecuado para maximizar el rendimiento sobre la producción de potencia con los ejercicios estudiados.

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Power-Load Curves in an Elite Weightlifter. A Case Study
Curvas de carga-potencia en un halterófilo de élite. Estudio de caso

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Abstract

Findings from mechanical power data can make a significant difference in the performance of athletes in weightlifting if it is properly understood by coaches. The purpose of this study was to examine the power-load (P-L) curve in the snatch, clean, back jerk and jerk of an international-level Spanish weightlifter. Four testing sessions were conducted in the present work. Session 1: estimating snatch and clean 1RM (1 repetition maximum); Session 2: power assessment of the snatch and clean across a spectrum of loads (30% to 100%) of the predetermined 1RM; Session 3: estimating back jerk and jerk 1RM; Session 4: power assessment of the back jerk and jerk across a spectrum of loads (30% to 100%) of the pre-determined 1RM. The highest peak power output (Pmax) was reached with loads of 90% of 1RM in each exercise tested, which demonstrated this percentage to be the optimal load (Pmax load) to train power development during weightlifting exercises.

Key words: snatch; clean; back jerk; jerk power; optimal load.

Resumen

El entendimiento por parte de los entrenadores de los datos de potencia mecánica obtenidos en la halterofilia puede marcar notables diferencias en el rendimiento de los atletas. El propósito de este estudio fue examinar la curva de carga-potencia en los ejercicios de arrancada, cargada, envión por detrás y envión en un halterófilo español de nivel internacional. Cuatro sesiones de evaluación fueron llevadas a cabo en este estudio. En la sesión 1 se estimó el 1RM (1 repetición máxima) en la arrancada y la cargada. En la sesión 2 se realizó una evaluación de la potencia alcanzada en la arrancada y la cargada en un espectro de cargas desde el 30% al 100% del 1RM predeterminado anteriormente. En la sesión 3 se estimó el 1RM en el envión por detrás y el envión. En la sesión 4 se realizó una evaluación de la potencia alcanzada en el envión por detrás y el envión en un espectro de cargas desde el 30% al 100% del 1RM predeterminado anteriormente. El pico de potencia mecánica fue alcanzado con el 90% del 1RM en cada uno de los ejercicios, mostrando dicho porcentaje como la carga óptima para el desarrollo de la potencia en ejercicios de halterofilia.

Palabras clave: arrancada; cargada, envión; envión por detrás; potencia; carga óptima.

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Introduction

The ability to develop high levels of muscular power is considered one of the main determinants of athletic performance, especially in sports that include throwing, jumping and sprinting actions, which require high force generation in a short period of time. (Castillo, Valverde, Morales, Pérez-Guerra, De León, and García-Manso, 2012; Comfort, Fletcher and McMahon, 2012a; Cormie, McGuigan and Newton, 2011; Kawamori and Haff, 2004; Suchomel, Comfort and Stone, 2015; Suchomel, Wright, Kernozek and Kline, 2014). To maximize the power output during any exercise there must be an optimum relationship between force and velocity. Consequently, the optimal load to achieve maximum peak power output, is the load that elicits maximum power production in a given movement (Cormie et al., 2011). From a practical point of view, the Pmax load and similar loads with no significant differences between them, the optimum power spectrum (Castillo et al., 2012), are considered the most appropriate stimuli to improve the power developed in a specific technical action (Soriano, Jiménez-Reyes, Rhea and Marín, 2015; Suchomel et al., 2015). Thus, to improve power production it is appropriate to use the Pmax load and similar loads achieved through multi-joint exercises, such as weightlifting exercises and their variations. According to this, searching for the Pmax load has a particular interest for strength and conditioning coaches.

Weightlifting exercises are one of the most effective ways to develop power output (Lake, Mundy and Comfort, 2014). In this sense, weightlifting exercises (snatch, clean & jerk) and their variants have proved to produce some of the highest average human power outputs among all resistance-training exercises (Garhammer, 1993; Hori, Newton, Nosaka and McGuigan, 2006; Kawamori and Haff, 2004; Kilduff, Bevan, Owen, Kingsley, Bunce, Bennett, and Cunningham, 2007; Stone, 1993). Therefore, in order to achieve a high level of performance, weightlifting exercises and their derivatives are generally used as training exercises in many sports (Hori, Newton, Nosaka and Stone, 2005; Janz and Malone, 2008) and in conditioning programmes (Comfort, Allen and Graham-Smith, 2011; Comfort, McMahon and Fletcher, 2013).

Weightlifting performance depends on how much weight the athlete can lift (one repetition maximum or 1RM), not how much power the athlete can produce. However, the importance of power production has been reported to be a key factor in this sport. On these lines, Stone, Pierce, Sands and Stone (2006), stated that power production is the most significant factor in determining success in weightlifting. Likewise, Hori et al. (2005) indicated that success in weightlifting depends on the power applied to the barbell against high loads (high-load speed strength). According to previous studies (Garhammer, 1993; Stone et al., 2006), during weightlifting the Pmax load is achieved with high loads: thus, the Pmax load is a key factor in achieving success during these types of exercise.

Although for many years researchers and coaches have been trying to gain knowledge about power production and Pmax loads in resistance exercises, the results have been inconclusive and the controversy still continues. Hence, the literature reports a wide range of Pmax loads (expressed as a percentage of 1RM) during weightlifting exercises and variants of these, ranging from 30% to 90% of 1RM (Comfort et al., 2012a; Flores et al., 2017; Garhammer, 1993; Haines, McBride, Skinner, Woodall, Larkin, Kirby and Dayne, 2010; Kilduff et al., 2007; Nacleiro, 2006; Pennington, Laubach De Marco and Linderman, 2010; Suchomel et al., 2014; Thomas, Kraemer, Spiering, Volek, Anderson and Maresh, 2007). This controversy in the literature may in part be explained by numerous methodological differences affecting the studies, the equipment used, and the inclusion of only the barbell or of the entire system mass in calculations (Cormie, McBride and McCaulley, 2007), the varying strength levels of participants (Baker, 2001), the type of training and fibers composition (Izquierdo, Häkkinen, González Badillo, Ibáñez and Gorostiaga, 2002; Romero, Vila, Ferragut and Alcaraz, 2009), and technical proficiency (Nacleiro, 2006). Furthermore, evidence-based knowledge of the use of weightlifting movements is limited in comparison with other studies where traditional resistance exercises like squats or bench presses have been evaluated. Thus, the search for Pmax loads during weightlifting exercises is of great interest for extending the knowledge of weightlifters, coaches and researchers, when designing training programmes that are more efficient and better adapted to the individual characteristics of the athlete.

One of the most widely used ways of discovering what improvements occur in power production is by means of strength-velocity (S-V), or power-load (P-L) curves, or both (Romero et al., 2009). However, there are no studies that show the exact load for achieving the Pmax load in weightlifting exercises, particularly with regard to elite level weightlifters. The present case offered an opportunity to examine a sports profile that is normally difficult for researchers to access (a senior Spanish record holder) in order to discover the type of loads on which the training of high performance weightlifters should focus. Therefore, the aim of the present study was to analyse and compare the P-L curve in snatch, clean, back jerk and jerk, so as to determine the optimal load (Pmax load) needed to achieve maximum peak power output (Pmax) in an elite Spanish weightlifter. In line with previous research findings (Flores et al., 2017; Garhammer, 1993; Haines et al., 2010), it was hypothesized that the Pmax load would be achieved toward the heavier end of the P-L curve for the snatch, clean, back jerk and jerk, and that a strong relationship would exist between the power values and Pmax load for the clean movement and jerk movement.

Methods

Participant

The participant in the study was an elite weightlifter, currently the senior Spanish record holder in clean & jerk (148 kg), and total (265 kg) as well as the former senior Spanish record in snatch (121 kg) in the 62 kg body weight category. According to his best weightlifting performance in competition his Sinclair coefficient was 387.76 (Sinclair, 1985). The descriptive characteristics of the participant and his best weightlifting performance are shown in Table 1. Prior to participating in the study, the athlete read and signed an informed consent protocol in accordance with guidelines set by the Human Subjects Review Committee at University of Salamanca. The study conformed to the principles of the World Medical Association's Declaration of Helsinki.

Table 1.- Descriptive data for the participant.

Age (years)	34.3
Height (m)	172.10
Body mass during the tests (kg)	63.8
Best snatch in competition (kg)	121
Best clean & jerk in competition (kg)	148
Best Total Olympic in competition (kg)	265
Best Sinclair coefficient in competition (62 kg category)	387.76
Weightlifting experience (years)	20.3

Procedures

The study was conducted during the first part of the 2015 season, in the month of January. Four test sessions were carried out in the weightlifter's usual training environment to assess 1RM and P-L curves for the snatch, clean, back jerk and jerk. Before the start of each test session, the participant went through a standardized warm-up composed of 5 minutes of light-intensity cycling followed by 5 minutes of series of dynamic stretches. After this general warm up, the participant engaged in 10 minutes of specific warm-up involving weightlifting movements with an unloaded barbell. In sessions one and two, the order of exercises assessed was first snatch, and second clean for both sessions. In sessions three and four the order of exercise assessed was first back jerk, and second jerk for both sessions. The selected order of the exercises was set taking into account the order used during competitions; first snatch, and second clean & jerk. Thus, snatch movement was always performed first and clean, jerk, or both were performed in the second place. In each session 10 minutes of rest were allowed between exercises. This recovery period is similar to that applied in weightlifting competitions between the snatch, and the clean & jerk movements. The study design is shown in Figure 1.

1RM testing (sessions one and three). The weightlifter's 1RM was obtained in accordance with the standardized protocol presented by Baechle and Earle (2008). The weightlifter had previously performed this test numerous times in conjunction with his normal training programme, for the purpose of monitoring strength development, and therefore he was fully familiar with the procedures of the test.

Power testing (sessions two and four). 2-4 days after his 1RM was established (the pause being intended to ensure an adequate recovery between sessions), a power test session was performed. After the warm-up exercise sets, the participant carried out a maximum effort repetition for each load, which was systematically increased through 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% of the participant's predetermined 1RM. The recovery period between loads was determined by the lifter, but was in all cases between 3 and 5 minutes.

Session	**1**		**2**		**3**		**4**
Objective	**1RM**	Rest (2/4 days)	**Power Test**	Rest (2/4 days)	**1RM**	Rest (2 to 4 days)	**Power Test**
Outline session	Warm up		Warm up		Warm up		Warm up
	SNATCH		**SNATCH**		**JERK**		**JERK**
	Rest (10 mins)		Rest (10 mins)		Rest (10 mins)		Rest (10 mins)
	CLEAN		**CLEAN**		**BACK JERK**		**BACK JERK**

Figure 1. Study Design.

Equipment

A 3-axis accelerometer (PS-2136A, PASCO, Roseville, CA) operating at 100Hz and a Bluetooth wireless device (Airlink 2 PS-2010, PASCO, Roseville, CA) were used in the power-testing sessions. The reliability of the results offered by these tests with the current measuring protocol has previously been validated (Flores, Sedano, de Benito and Redondo, 2016). This device was chosen for its easy portability in the weights room and minimum disturbance to the flow of the lifting sessions without compromising the weightlifter's technique in data collection (Sato, Smith and Sands, 2009). The accelerometer was placed with a foam unit underneath and in alignment with the long axis of the barbell on the left edge of the bar in relation to the lifter's position (Figure 3). In that position, backward-and-forward, side-to-side, and up-and-down bar movements are equivalent to the X, Y and Z axes respectively, in accordance with the factory configuration. Prior to each attempt, the position of the sensor unit was checked and, if necessary, restored to the configuration described above. The total mass of the measuring device plus the protective foam was 180 g, which is equivalent to a metal barbell collar (Sato et al., 2009). This weight is not enough to induce asymmetric disturbances during a lift.

Data Collection and Analysis

The data were processed thereafter, using Pasco Capstone software (Version 1.1.5, Pasco Scientific PASCO, Roseville, CA) and barbell peak power outputs were calculated from acceleration in accordance with the methodology explained by Thompson and Bemben (1999). In accordance with Flores et al. (2016), data analysis included only the vertical acceleration attained by the barbell that was lifted, and only up to the finish of pull phase for snatch and clean, and up to the highest point of the bar's path before the catch position for back jerk and jerk. It should be noted that the lifter's body weight was not included in the calculations, so that the power calculations recorded the work done against the bar by the lifter. This exclusion of the body weight in the calculations gives more crucial information about weightlifting performance, because the success of weightlifting depends on the power applied to the barbell, which moves independently of the body, and on how high the lifter can pull the barbell (in the snatch and clean) or drive it (in the jerk), regardless of the lifter's body mass (Hori et al., 2006; Hori et al., 2007; Kawamori et al., 2005; McBride et al., 2011). In that sense, specific measurement of the power applied to the barbell may be the primary outcome measure when assessing weightlifting performance (Hori et al., 2006; Hori et al., 2007; Kawamori et al., 2005; McBride et al., 2011).

Figure 2. Weightlifter performing the lift with the accelerometer fixed to the bar as in Flores et al. (2016).

Hook grip, weightlifting belt, weightlifting shoes and chalk, were allowed for use by the participant, but weightlifting straps were not allowed. In both testing sessions, strong verbal encouragement was given to the participant to motivate him to perform each lift to the maximum and as powerfully as possible, so as to reach his top performance.

Results

Table 2 shows the data for each exercise during the power test session. Figure 2 presents the participant's P-L curve analysed in the snatch, clean, back jerk and jerk exercises. Peak power of the snatch, clean & jerk increased progressively from 30% to 90% of 1RM and decreased strongly with the 1RM of the participant. The P-L curve of the back jerk showed two peaks, one with 60% and the other with 90% of 1RM. During the four movements assessed, the lifter achieved the Pmax load with 90% of 1RM.

Table 2.- Descriptive data for power for snatch, clean, back jerk and jerk for each power test session.

	Pmax (W)			
Load (% 1RM) *	Snatch	Clean	Back Jerk	Jerk
30	1657.78	1129.89	1600.16	1137.71
40	2016.63	2008.75	1817.56	1294.27
50	2333.24	2182.10	2744.06	2031.18
60	2670.43	2312.92	3075.14	2165.43
70	2835.87	2490.06	2916.11	2367.70
80	3072.66	2720.23	3101.71	2491.00
90	3383.19	2945.90	3480.88	2963.82
100	2716.78	2560.60	3077.05	2657.91

* RM = repetition maximum

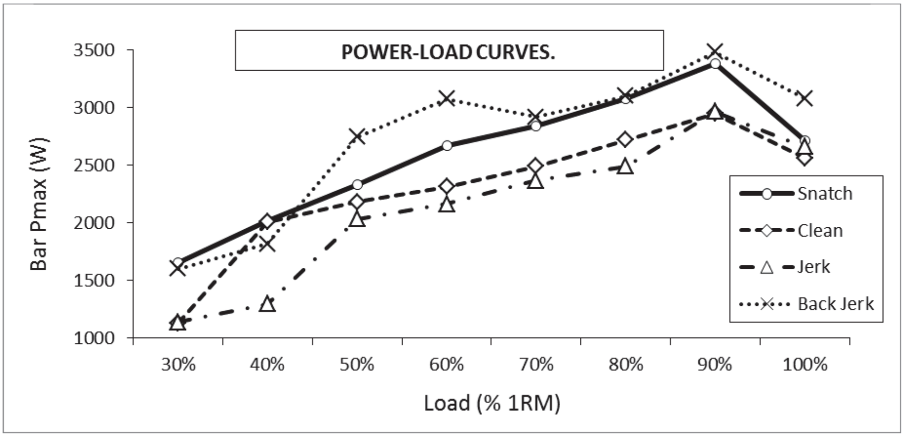

Figure 3.- P-L Curve of snatch, clean, back jerk and jerk. Pmax at loads of 30-100% of one repetition maximum (1RM).

The differences in bar velocity to achieve the Pmax load are shown in Figure 3, the snatch exercise being the movement where the bar velocity reached the highest value with 2.41 m/s.

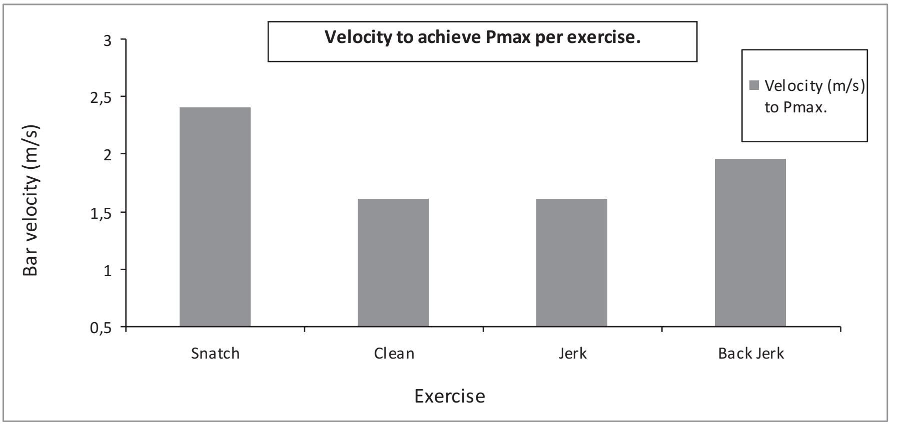

Figure 4.- Maximum bar velocity achieved per exercise tested.

Discussion

The purpose of this research was to describe and compare the P-L curve in snatch, clean, back jerk and jerk, so as to determine the optimal load (Pmax load) to achieve maximum peak power output (Pmax) in an elite Spanish weightlifter.

During weightlifting exercises, the centre of gravity of the barbell and the system (bar plus body mass) move independently of one another (Cormie et al., 2007; Hori et al., 2006; Hori et al., 2007; McBride et al., 2011). According to this, one of the weightlifter's interests is to move an external object, the bar plus weight, as fast as possible because success in weightlifting depends on the power applied to the barbell (Haines et al., 2010; Hori et al., 2006; McBride et al., 2011). Thus, only the power applied to the barbell was taken into account in the case under study. In this regard, taking into account only the power applied to the barbell, Pmax load during weightlifting exercises and their derivatives has been reported as ranging from 70% to 90% of 1RM. (Flores et al., 2017; Haines et al., 2010; Hori et al., 2006; Nacleiro, 2006). In the present study, the P-L curve showed Pmax loads with intensities of 90% of 1RM for all the exercises assessed. These results are consistent with the findings noted by McBride et al. (2011), who found 90% of 1RM as the Pmax load with experienced strength athletes during power clean and by Flores et al. (2017), who also reported 90% of 1RM as the Pmax load during the jerk and back jerk in a group of competitive weightlifters.

On the other hand, the findings of the current study are in contrast to some previous studies where the Pmax load during hang pulls and mid-thigh pulls was reported with significantly lower percentages of 1RM, ranging from 30% to 60% (Comfort et al., 2012b; Thomas et al., 2007). Although Olympics pulls are variants of weightlifting exercises, it is likely that the higher loads (90% 1RM) identified in the current study to elicit Pmax during snatch, clean, back jerk and jerk are a result of the additional phases during the whole movement, permitting greater time and range of motion for accelerating the bar, technically unloading the bar because of its momentum (Comfort et al., 2012b). However, these differences should be interpreted with caution, because different systems for recording data and varying methodologies have been used for power calculations.

The lifter tested achieved the highest Pmax values during back jerk (3480.88 W) followed closely by the snatch (3383.19 W). It would appear that to date only one study (Flores et al., 2017) has studied Pmax values during back jerk. In that study, jerk and back jerk Pmax were compared, and the findings were in line with the current work, the highest Pmax being achieved during back jerk. The lowest Pmax was recorded for the clean (2945.89 W) and the jerk (2963.82 W), being almost equal for these two exercises. This finding is supported by previous research carried out by Garhammer (1993) and Suchomel et al. (2015), who reported that Pmax values during second pull of clean & jerk were very similar in magnitude for elite lifters in top physical condition. Although Pmax values were almost equal during snatch and back jerk (Figure 3), the bar velocity noted in achieving these Pmax values was clearly different, standing at 2.41 m/s for the snatch and 1.96 m/s for the back jerk (Figure 4). This important difference in bar velocities between the snatch and back jerk shows how in the first movement Pmax is reached with a greater bar velocity, while in the second it is the opposite, a slower strength-related movement.

During the current study, horizontal work was left out of consideration in all exercises assessed, account being taken only of the vertical component, in accordance with the methodology previously validated by Flores et al. (2016). According to Garhammer (1993), the horizontal work produced during the second pull in snatch and clean by a lifter of a light weight division, like the participant studied, represents a small component, less than 5%, of the total work produced. On the other hand, during the jerk exercise, Garhammer (1993) claimed that the horizontal work can always be neglected for skilled lifters, as in the case of the athlete studied. This ruling out of the horizontal component of work during the current study should be kept in mind when comparing work in which both horizontal and vertical components were studied.

It is of interest to note that the percentages needed to elicit Pmax loads in the present work are likely to have been influenced by the profile of the participant studied (an elite Spanish weightlifter). The type of training and fibers composition, as well as the level of experience and proficiency of the participant, could shift the percentage of 1RM at which the highest power is produced either upwards or downwards (Izquierdo et al. 2002; Kawamori and Haff, 2004; Nacleiro, 2006). In the present case, such factors include the probable predominance of fast twitch fibers, the background of the weightlifter studied in respect of technique, and the type of training usually undertaken in the sport of weightlifting, which focuses on applying high speed to the bar at high loads (Campos, Poletaev, Cuesta, Pablos, Carratala, 2006). These might contribute to a shift upwards in the percentage of 1RM needed to achieve Pmax (Nacleiro, 2006).

The P-L curve for back jerk showed a different trend from the other three exercises assessed, with two different peaks on the curve, at 60% and 90% (Figure 3). Although no clear explanation can be given for the different trend shown during back jerk in comparison with the other three movements assessed, it may be hypothesized that this difference emerged from the varying background of technique in these several exercises. Thus, snatch, clean, and jerk are the competitive weightlifting movements which are in constant use by the participant tested, while back jerk is an auxiliary non-competitive exercise which is used much less frequently (not more than once a week in the case of the weightlifter studied), which perhaps led to less technical consistency in this exercise.

In light of the results, the athlete studied should prioritize during his training work with loads close to 90% of the 1RM in the snatch, clean, back jerk and jerk exercises, because these percentages represent the Pmax load to achieve Pmax for the weightlifter studied. This percentage (90%) represents a crucial part of the athlete's training, since the use of this intensity has been reported as a determining factor for success in weightlifting (González-Badillo, 1991). On the basis of the results obtained, the weightlifter studied should continue to focus on working with this range of percentages.

In order to detect possible variations in the results obtained, it would be of interest to periodize the evaluation of the athlete at least once a year. A greater frequency than this would not be necessary, since the tendency to modify the location of the Pmax load indicates that this variable needs longer periods of time (several years) to evince any major changes, although possibly these would occur more rapidly in less well trained subjects or those with lower levels of strength (Nacleiro, 2006), this not being the case for the participant studied.

The findings of this study should be considered in light of two limitations. Firstly, the peak powers shown are referred only to the bar, although it is true that McBride et al. (2011) state that there is little difference between calculating the bar, the body or the system (lifter-plus-bar) power during weightlifting movements. Secondly, this investigation was limited to one case, an elite Spanish weightlifter. Thus, the findings of this study are applicable to the participant studied, but may not be valid for others.

Conclusion

It would appear that nobody has attempted to describe P-L curves including 100% of 1RM during snatch, clean, back jerk and jerk in an elite weightlifter. Likewise, there is a need for further studies describing what P–L curves during weightlifting exercises should be like for different sports and levels where power training is a determinant factor, as is the case of weightlifting. On the basis of the outcomes of this investigation, and extrapolating only to the sample studied, it might be concluded that the weightlifter analysed in the snatch, clean, back jerk and jerk shows a P-L curve whose maximum peak power (Pmax) is reached with 90% of 1RM for all exercises cited, identifying this percentage as the optimal load (Pmax load) for achieving maximum peak power output (Pmax), this percentage therefore being the best stimulus to develop and train power.

References

Baechle, T. R., & Earle, R. W. (2008). Essentials of strength training and conditioning *Human Kinetics*.

Baker, D. (2001). A series of studies on the training of high-intensity muscle power in rugby league football players. *Journal of Strength and Conditioning Research*, *15*(2), 198-209. https://doi.org/10.1519/00124278-200105000-00008

Baker, D.; Nance, S., & Moore, M. (2001a). The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *Journal of Strength and Conditioning Research*, *15*(1), 20-24. https://doi.org/10.1519/00124278-200102000-00004

Baker, D.; Nance, S., & Moore, M. (2001b). The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *Journal of Strength and Conditioning Research*, *15*(1), 92-97. https://doi.org/10.1519/00124278-200102000-00016

Campos, J.; Poletaev, P.; Cuesta, A.; Pablos, C., & Carratala, V. (2006). Kinematical analysis of the snatch in elite male junior weightlifters of different weight categories. *Journal of Strength and Conditioning Research*, *20*(4), 843-850.

Castillo, F.; Valverde, T.; Morales, A.; Pérez-Guerra, A.; De León, F., & García-Manso, J. (2012). Maximum power, optimal load and optimal power spectrum for power training in upper-body (bench press): A review. *Revista Andaluza de Medicina del Deporte*, *5*(1), 18-27. https://doi.org/10.1016/S1888-7546(12)70005-9

Comfort, P.; Allen, M., & Graham-Smith, P. (2011). Comparisons of peak ground reaction force and rate of force development during variations of the power clean. *Journal of Strength and Conditioning Research*, *25*(5), 1235-1239. https://doi.org/10.1519/JSC.0b013e3181d6dc0d

Comfort, P.; Fletcher, C., & McMahon, J. J. (2012a). Determination of optimal loading during the power clean, in collegiate athletes. *Journal of Strength and Conditioning Research*, *26*(11), 2970-2974. https://doi.org/10.1519/JSC.0b013e318245bed4

Comfort, P.; McMahon, J. J., & Fletcher, C. (2013). No kinetic differences during variations of the power clean in inexperienced female collegiate athletes. *Journal of Strength and Conditioning Research*, *27*(2), 363-368. https://doi.org/10.1519/JSC.0b013e31825489c6

Comfort, P.; Udall, R., & Jones, P. A. (2012b). The effect of loading on kinematic and kinetic variables during the midthigh clean pull. *Journal of Strength and Conditioning Research*, *26*(5), 1208-1214. https://doi.org/10.1519/JSC.0b013e3182510827n

Cormie, P.; McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power. *Sports Medicine*, *41*(1), 17-38. https://doi.org/10.2165/11537690-000000000-00000

Cormie, P.; McBride, J. M., & McCaulley, G. O. (2007). The influence of body mass on calculation of power during lower-body resistance exercises. *Journal of Strength and Conditioning Research*, *21*(4), 1042-1049. https://doi.org/10.1519/00124278-200711000-00011

Flores, F. J.; Sedano, S., & Redondo, J. C. (2017). Optimal load and power spectrum during jerk and back jerk in competitive weightlifters. *Journal of Strength and Conditioning Research*, *31*(3), 809-816. https://doi.org/10.1519/JSC.0000000000001544

Flores, F. J.; Sedano, S.; de Benito, A. M., & Redondo, J. C. (2016). Validity and reliability of a 3-axis accelerometer for measuring weightlifting movements. *International Journal of Sports Science and Coaching*, *11*(6), 872-879. https://doi.org/10.1177/1747954116676114

Garhammer, J. (1993). A review of power output studies of olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *Journal of Strength and Conditioning Research*, *7*(2), 76-89. https://doi.org/10.1519/00124278-199305000-00002

González-Badillo, J.J. (1991). *Halterofilia. Comité Olímpico Español.*

Haines, T.; McBride, J. M.; Skinner, J.; Woodall, M.; Larkin, T. R.; Kirby, T. J., & Dayne, A. M. (2010). Effect of load on bar, body and system power output in the power clean. *Journal of Strength and Conditioning Research*, *24*, 1.

Hori, N.; Newton, R. U.; Nosaka, K., & McGuigan, M. R. (2006). Comparison of different methods of determining power output in weightlifting exercises. *Strength and Conditioning Journal*, *28*(2), 34-40. https://doi.org/10.1519/00126548-200604000-00006

Hori, N.; Newton, R. U.; Nosaka, K., & Stone, M. H. (2005). Weightlifting exercises enhance athletic performance that requires high-load speed strength. *Strength and Conditioning Journal*, *27*(4), 50-55. https://doi.org/10.1519/00126548-200508000-00008

Hori, N.; Newton, R. U.; Andrews, W. A.; Kawamori, N.; McGuigan, M. R., & Nosaka, K. (2007). Comparison of four different methods to measure power output during the hang power clean and the weighted jump squat. *Journal of Strength and Conditioning Research*, *21*(2), 314-320. https://doi.org/10.1519/00124278-200705000-00005

Izquierdo, M.; Häkkinen, J.; González-Badillo, J. J.; Ibañez, J., & Gorostiaga, E. M. (2002). Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. *European Journal of Applied Physiology*, *87*, 264-271. https://doi.org/10.1007/s00421-002-0628-y

Janz, J., & Malone, M. (2008). Training explosiveness: Weightlifting and beyond. *Strength and Conditioning Journal*, *30*(6), 14-22. https://doi.org/10.1519/SSC.0b013e31818e2f13

Kawamori, N.; Crum, A. J.; Blumert, P. A.; Kulik, J. R.; Childers, J. T.; Wood, J. A., & Haff, G. G. (2005). Influence of different relative intensities on power output during the hang power clean: Identification of the optimal load. *Journal of Strength and Conditioning Research*, *19*(3), 698-708. https://doi.org/10.1519/00124278-200508000-00035

Kawamori, N., & Haff, G. G. (2004). The optimal training load for the development of muscular power. *Journal of Strength and Conditioning Research*, *18*(3), 675-684. https://doi.org/10.1519/00124278-200408000-00051

Kilduff, L. P.; Bevan, H.; Owen, N.; Kingsley, M. I.; Bunce, P.; Bennett, M., & Cunningham, D. (2007). Optimal loading for peak power output during the hang power clean in professional rugby players. *International Journal of Sports Physiology and Performance*, *2*(3), 260-269. https://doi.org/10.1123/ijspp.2.3.260

Lake, J. P.; Mundy, P. D., & Comfort, P. (2014). Power and impulse applied during push press exercise. *Journal of Strength and Conditioning Research*, *28*(9), 2552-2559. https://doi.org/10.1519/JSC.0000000000000438

McBride, J. M.; Haines, T. L., & Kirby, T. J. (2011). Effect of loading on peak power of the bar, body, and system during power cleans, squats, and jump squats. *Journal of Sports Sciences*, *29*(11), 1215-1221. https://doi.org/10.1080/02640414.2011.587444

Nacleiro, F. (2006). Análisis de la fuerza y la potencia mecánica producida en los ejercicios con resistencias en diferentes poblaciones de deportistas a lo largo de una temporada. (Doctoral dissertation).

Pennington, J.; Laubach, L.; De Marco, G., & Linderman, J. (2010). Determining the optimal load for maximal power output for the power clean and snatch in collegiate male football players. *Journal of Exercise Physiology*, *13*(2), 10-20.

Romero, S.; Vila, H.; Ferragut, C., & Alcaraz, P. E. (2009). Power-strength curve in basketball players. *Revista de Psicología del Deporte*, *18*(3), 425-428.

Sato, K.; Smith, S. L., & Sands, W. A. (2009). Validation of an accelerometer for measuring sport performance. *Journal of Strength and Conditioning Research*, *23*(1), 341-347. https://doi.org/10.1519/JSC.0b013e3181876a01

Sinclair, R. (1985). Normalizing the performance of athletes in Olympic weightlifting. *Canadian Journal of Applied Sport Sciences*, *10*(2), 94-98.

Soriano, M. A.; Jiménez-Reyes, P.; Rhea, M. R., & Marín, P. J. (2015). The optimal load for maximal power production during lower-body resistance exercises: A meta-analysis. *Sports Medicine*, *45*(8), 1191-1205. https://doi.org/10.1007/s40279-015-0341-8

Stone, M. H.; O'Bryant, H. S.; Mccoy, L.; Coglianese, R.; Lehmkuhl, M., & Schilling, B. (2003). Power and maximum strength relationships during performance of dynamic and static weighted jumps. *Journal of Strength and Conditioning Research*, *17*(1), 140–147. https://doi.org/10.1519/00124278-200302000-00022

Stone, M. H. (1993). Position statement: Explosive exercise and training. *Strength and Conditioning Journal*, *15*(3), 7-15. https://doi.org/10.1519/0744-0049(1993)015<0007:EEAT>2.3.CO;2

Stone, M. H.; Pierce, K. C.; Sands, W. A., & Stone, M. E. (2006). Weightlifting: A brief overview. *Strength and Conditioning Journal*, *28*(1), 50-66. https://doi.org/10.1519/00126548-200602000-00010

Suchomel, T. J.; Comfort, P., & Stone, M. H. (2015). Weightlifting pulling derivatives: Rationale for implementation and application. *Sports Medicine*, *45*(6), 823-839. https://doi.org/10.1519/00126548-200602000-00010

Suchomel, T. J.; Wright, G. A.; Kernozek, T. W., & Kline, D. E. (2014). Kinetic comparison of the power development between power clean variations. *Journal of Strength and Conditioning Research*, *28*(2), 350-360. https://doi.org/10.1519/JSC.0b013e31829a36a3

Thomas, G. A.; Kraemer, W. J.; Spiering, B. A.; Volek, J. S.; Anderson, J. M., & Maresh, C. M. (2007). Maximal power at different percentages of one repetition maximum: Influence of resistance and gender. *Journal of Strength and Conditioning Research*, *21*(2), 336-342. https://doi.org/10.1519/00124278-200705000-00008

Thompson, C. J., & Bemben, M. G. (1999). Reliability and comparability of the accelerometer as a measure of muscular power. *Medicine and Science in Sports Exercise*, *31*(6), 897-902. https://doi.org/10.1097/00005768-199906000-00020

CONCLUSIONES Y APLICACIONES PRÁCTICAS

CONCLUSIONES Y APLICACIONES PRÁCTICAS

En función de los resultados obtenidos en los cuatro artículos publicados en esta tesis doctoral y del análisis realizado en la discusión de los mismos, las principales conclusiones y aplicaciones prácticas que se pueden extraer de estos estudios son:

PRIMERA: El acelerómetro comercial de 3 ejes (PS-2136A, PASCO, Roseville, Calif) ha sido validado con resultados satisfactorios en el plano vertical (eje Z) durante toda la fase del tirón (incluyendo primer tirón, transición y segundo tirón) en los ejercicios de arrancada y cargada de fuerza y hasta el punto más alto de la trayectoria de la barra antes de la fijación o recepción de la barra en el ejercicio de yerk (incluyendo las fases de flexión, extensión y split).

SEGUNDA: El dispositivo y protocolo validado (PS-2136A, PASCO, Roseville, Calif) es sencillo de usar, manejar y de poner en práctica. Además, este sistema tiene un bajo coste comercial lo cual facilita su acceso a entrenadores para su utilización diaria en el trabajo de campo con sus deportistas fuera de un entorno de laboratorio.

TERCERA: La carga óptima para alcanzar la máxima potencia mecánica (pico) con levantadores de nivel competitivo nacional en el ejercicio de yerk, se localiza con el 90% del 1RM. Y el espectro óptimo de cargas, para el desarrollo de la máxima potencia con este ejercicio y levantadores de este nivel de rendimiento, se sitúa entre el 80% y el 90% del 1RM.

CUARTA: La carga óptima para alcanzar la máxima potencia mecánica (pico) con levantadores de nivel competitivo nacional en el ejercicio de yerk tras-nuca, se localiza con el 90% del 1RM. Y el espectro óptimo de cargas, para el desarrollo de la máxima potencia con este ejercicio y levantadores de este nivel de rendimiento, se sitúa entre el 80% y el 90% del 1RM.

QUINTA: La carga óptima para alcanzar la máxima potencia mecánica (pico) con levantadores de nivel internacional en el ejercicio de arrancada, se localiza con el 90% del 1RM. Y el espectro óptimo de cargas, para el desarrollo de la máxima potencia con este ejercicio y levantadores de este nivel de rendimiento, se sitúa entre el 80% y el 90% del 1RM.

SEXTA: La carga óptima para alcanzar la máxima potencia mecánica (pico) con levantadores de nivel internacional en el ejercicio de cargada, se localiza con el 90% del 1RM. Y el espectro óptimo de cargas, para el desarrollo de la máxima potencia con este ejercicio y levantadores de este nivel de rendimiento, no fue localizado entre ninguna de las cargas evaluadas, existiendo por tanto diferencias significativas entre la carga óptima (90% del 1RM) y todo el espectro de cargas estudiado (30%-80% del 1RM).

SEPTIMA: La carga óptima para alcanzar la máxima potencia mecánica (pico) con levantadores de nivel competitivo nacional en el ejercicio de arrancada, se localiza con el 70% del 1RM. Y el espectro óptimo de cargas, para el desarrollo de la máxima potencia con este ejercicio y levantadores de este nivel de rendimiento, se sitúa entre el 70% y el 90% del 1RM.

OCTAVA: La carga óptima para alcanzar la máxima potencia mecánica (pico) con levantadores de nivel competitivo nacional en el ejercicio de cargada, se localiza en el 90% del 1RM. Y el espectro óptimo de cargas, para el desarrollo de la máxima potencia con este ejercicio y levantadores de este nivel de rendimiento, se sitúa entre el 50% y el 90% del 1RM.

NOVENA: En términos absolutos el ejercicio de arrancada genera valores de potencia máxima (pico) más altos que la cargada tanto para levantadores de nivel internacional como para levantadores de nivel competitivo nacional tanto con la carga óptima como en todas y cada una de las cargas estudiadas (30%-90% del 1RM).

DÉCIMA: En términos absolutos el ejercicio de yerk tras-nuca genera valores de potencia máxima (pico) más altos que el yerk con levantadores de nivel competitivo nacional tanto con la carga óptima como en todas y cada una de las cargas estudiadas (30%-90% del 1RM).

UNDÉCIMA: En términos absolutos el ejercicio de yerk tras-nuca genera valores de potencia máxima (pico) más altos que el yerk con levantadores de nivel competitivo nacional tanto con la carga óptima como en todas y cada una de las cargas estudiadas (30%-90% del 1RM).

DUODÉCIMA: Los resultados de nuestra investigación indican que los levantadores de nivel internacional tienden localizar la carga óptima para alcanzar la máxima potencia mecánica y el espectro óptimo de cargas para el desarrollo de esta, en la parte superior de la curva carga-potencia (80%-90% del 1RM). Mientras que los levantadores de menor nivel competitivo localizan la carga óptima con el 90% del 1RM en todos los ejercicios excepto en la arrancada (70% del 1RM), aunque muestran un espectro de cargas óptimo mucho más amplio; 50% - 90% del 1RM en el ejercicio de cargada y 70% - 90% del 1RM en el ejercicio de arrancada.

BIBLIOGRAFÍA

BIBLIOGRAFÍA

1. Abernethy, P, Wilson, G, & Logan, P. Strength and power assessment. Issues, controversies and challenge. *Sports Medicine* 19: 401-417, 1995.

2. Alcaraz, PE, Romero-Arenas, S, Vila, H, & Ferragut, C. Power–load curve in trained sprinters. *Journal of Strength and Conditioning Research* 25: 3045–3050, 2011.

3. Asçi, A, & Açikada, C. Power production among different sports with similar maximum strength. *Journal of Strength and Conditioning Research* 21: 10-16, 2007.

4. Aullana, J. Aclaración de términos y conceptos utilizados en el entrenamiento de la fuerza explosiva*. Kronos* 14: 1-29, 2015.

5. Baker, D. A series of studies on the training of high-intensity muscle powerin rugby league football players. *Journal of Strength and Conditioning Research 15*: 198-209, 2001.

6. Baker, D, Nance, S, & Moore, M. The load that maximizes the average mechanical power output during explosive bench press throws in highly trained athletes. *Journal of Strength and Conditioning Research* 15: 20-24, 2001.

7. Baker, D, Nance, S, & Moore M. The load that maximizes the average mechanical power output during jump squats in power-trained athletes. *Journal of Strength and Conditioning Research* 15: 92–97, 2001.

8. Bevan, HR, Bunce, PJ, Owen, NJ, Bennett, MA, Cook, CJ, Cunningham, DJ, Newton, RU, & Kildulff, LP. Optimal loading for the development of peak power output in professional rugby players. *Journal of Strength and Conditioning Research* 24: 43-47 2010.

9. Bompa, TO. Periodización: teoría y metodología del entrenamiento. L'Hospitalet de Llobregat, B: *Hispano Europea*, 2003.

10. Castillo F. Carga óptima para el desarrollo de la potencia máxima en jóvenes tenistas durante ejercicios de media sentadilla y press banca, (Master's thesis). University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria (Spain), 2012.

11. Castillo, F, Valverde, T, Morales, A, Pérez-Guerra, De León, F, & García-Manso, J. Maximum power, optimal load and optimal power spectrum for power training in upper-body (bench press): A review. *Revista Andaluza de Medicina del Deporte* 5: 18–27, 2012.

12. Comfort, P, Allen, M, & Graham-Smith, P. Comparisons of peak ground reaction force and rate of forcé development during variations of the power clean. *Journal of Strength and Conditioning Research* 25: 1235–1239, 2011.

13. Comfort, P, McMahon, JJ, & Fletcher, C. No kinetic differences during variations of the power clean in inexperienced female collegiate athletes. *Journal of Strength and Conditioning Research* 27: 363–368, 2013.

14. Cormie, P, McGuigan, MR, & Newton, RU. Developing maximal neuromuscular power. *Sports Medicine* 41: 17–38, 2011.

15. Cormie, P, McBride, JM, & McCaulley, GO. Validation of power measurement techniques in dynamic lower body resistance exercises. *Journal Applied Biomechanics* 23, 103-118, 2007.

16. Cormie, P, McCaulley, GO, Triplett, NT, & McBride, JM. Optimal loading for maximal power output during lower-body resistance exercises. *Medicine and Science in Sports Exercise* 39: 340-349, 2007.

17. Cronin, JB, McNair, PJ, & Marshall, RN. Developing explosive power: a comparison of technique and training. *Journal of Science and Medicine in Sport* 4: 59-70, 2001.

18. Cronin, J, & Sleivert, G. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Medicine* 35: 213-234, 2005.

19. Cronin, JB, McNair, PJ, & Marshall, RN. The role of maximal strength and load on initial power production. *Medicine and Science in Sports Exercise* 32: 1763-1769, 2000.

20. Dugan, EL, Doyle, TLA, Humphries, B, Hasson, CJ, & Newton, RU. Determining the optimal load for jump squats: a review of methods and calculations. *Journal of Strength and Conditioning Research* 18: 668-674, 2004.

21. Faulkner, JA, Claflin, DR, & McCully, KK. Power output of fast and slow fibers from human skeletal muscles. In: Jones, NL, et al. Human muscle power. Champaign, IL: *Human Kinetics*, 81–94, 1986.

22. Garhammer, J. Power production by olympic weightlifters. *Medicine and Science in Sports Exercise* 12: 54-60, 1980.

23. Garhammer, J. A comparison of maximal power outputs between elite male and female weightlifters in competition. *International Journal of Sport Biomechanics* 7: 3-11, 1991.

24. Garhammer, J. A review of power output studies of olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *Journal of Strength and Conditioning Research* 7: 76-89, 1993.

25. González-Badillo, JJ, & Gorostiaga, EG. Fundamentos del entrenamiento de la fuerza. Aplicación al alto rendimiento deportivo. Barcelona, B: *Inde*, 1995.

26. Haff, GG, & Potteiger, JA. A brief review: explosive exercises and sports performance. *Strength & Conditioning Journal* 23: 13–20, 2001.

27. Haff, GG, Stone, M, O'Bryant, HS, Harman, E, Dinan, C, Johnson, R, & Han, KH. Force-time dependent characteristics of dynamic and isometric muscle actions. *Journal of Strength and Conditioning Research* 11: 269-272, 1997.

28. Harris, NK, Cronin, JB, & Hopkins, WG. Power outputs of a machine squatjump across a spectrum of loads. *Journal of Strength and Conditioning Research* 21: 1260-1264, 2007.

29. Harris, GR, Stone, MH, O'Bryant, HS, Proulx, CM, & Johnson, RL. Short-term performance effects of high power, high force, or combined weight-training methods. *Journal of Strength and Conditioning Research* 14: 14–20, 2000.

30. Hori, N, Newton, RU, Andrews, WA, Kawamori, N, Mcguigan, MR, & Nosaka, K. Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction?. *Journal of Strength and Conditioning Research* 22: 412–418, 2008.

31. Izquierdo, M, Ibáñez, J, Gorostiaga, EM, Zúñiga, A, Antón, A, Larrion, JL, & Häkkinen, K. 1999. Maximal strength and power characteristics in isometric and dynamic actions of the upper and lower extremities in middle-aged and older men. *Acta Physiologica Scandinavica* 167: 57-68, 1999.

32. Izquierdo, M, Häkkinen, K, González-Badillo, JJ, Ibáñez, J, & Gorostiaga, EM. Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. *European Journal of Applied Physiology* 87: 264-271, 2002.

33. Jandacka, D, & Uchytil, J. Optimal load maximizes the mean mechanical power output during upper extremity exercise in highly trained soccer players. *Journal of Strength and Conditioning Research* 25: 2764-2772, 2011.

34. Jandacka, D, & Vaverka, F. A regression model to determine load for máximum power output. *Sports Biomechanics* 7: 361-371, 2008.

35. Josepshon, RK. Contraction dynamics and power output of skeletal muscle. *Annual Reviews of Physiology* 55: 527–546, 1993.

36. Kaneko, M, Fuchimoto, T, Toji, H, & Suei, K. Training effect of different loads on the force-velocity relationship and mechanical power output in human muscle. *Scandinavian Journal of Sports Sciences* 5: 50–55, 1983.

37. Kawamori, N, Crum, AJ, Blumert, PA, Kulik, JR, Childers, JT, Wood, JA, Stone, MH, & Haff, GG. Influence of different relative intensities on power output during the hang power clean: identification of the optimal load. *Journal of Strength and Conditioning Research* 19: 698-708, 2005.

38. Kawamori, N, & Haff, GG. The optimal training load for the development of muscular power. *Journal of Strength and Conditioning Research* 18: 675–684, 2004.

39. Kawamori, N, Rossi, SJ, Justice, BD, Haff, EE, Pistilli, EE, O'Bryant, HS, Stone, MH, & Haff, GG. Peak force and rate of forcé development during isometric and dynamic mid-thigh clean pulls performed at various intensities. *Journal of Strength and Conditioning Research* 20: 483-491, 2006.

40. Kilduff, L, Bevan, H, Owen, N, Kingsley, M, Bunce, P, Bennett, M, & Cunningham, D, 2007. Optimal loading for peak power output during the hang power clean in professional rugby players. *International Journal of Sports Physiolgy and Performance* 2: 260-269, 2007.

41. Knuttgen, HG, & Kraemer, WJ. Terminology and measurement in exercise performance. *Journal of Strength and Conditioning Research* 1: 1-10, 1987.

42. Komi, PV. Strength and power in sport. Oxford, OX: *Blackwell Scientific*, 2003.

43. Kraemer, WJ, & Ratamess, NA. Fundamentals of resistance training: progression and exercise prescription. *Medicine and Science in Sports and Exercise* 36: 674-688, 2004.

44. Lake, JP, Mundy, PD, & Comfort, P. Power and impulse applied during push press exercise. *Journal of Strength and Conditioning Research* 28: 2552-2559, 2014.

45. Marqués, MC, Van Den Tillaar, R, Vescovi, JD, & González-Badillo, JJ. Relationship between throwing velocity, muscle power, and bar velocity during bench press in elite handball players. *International Journal of Sports Physiolgy and Performance* 2: 414-422, 2007.

46. Mastropaolo, JA. A test of maximum power stimulus theory for strength. *European Journal of Applied Physiology* 65: 415–420, 1992.

47. Mayhew, J, Ware, J, Johns, R, & Bemben, M. Changes in upper body power following heavy-resistance strength training in college men. *International Journal of Sports Medicine* 18: 516-520, 1997.

48. McBride, JM, Haines, TL, and Kirby, TJ. Effect of loading on peak power of the bar, body, and system during power cleans, squats, and jump squats. *Journal of Sports Sciences* 29: 1215-1221, 2011.

49. McBride, JM, Triplett-McBride, T, Davie, A, & Newton, RU. A comparison of strength and power characteristics between power lifters, olympic lifters, and sprinters. *Journal of Strength and Conditioning Research* 13: 58-66, 1999.

50. McBride, JM, Triplett-McBride, T, Davie, A, & Newton, RU. The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed. *Journal of Strength and Conditioning Research* 16: 75–82, 2002.

51. Moritani, T. Neuromuscular adaptations during the acquisition of muscle strength, power and motor tasks. *Journal of Biomechanics* 26: 95–107, 1993.

52. Moss, BM, Refsnes, PE, Ablidgaard, A, Nicolaysen, K, & Jensen, J. Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load power and load-velocity relationships. *European Journal of Applied Physiology* 75: 193–199, 1997.

53. Nacleiro, F. Análisis de la fuerza y la potencia mecánica producida en los ejercicios con resistencias en diferentes poblaciones de deportistas a lo largo de la temporada, (Master's thesis). University of León, León (Spain), 2006.

54. Newton, RU, & Kraemer WJ. Developing explosive muscular power: implications for a mixed methods training strategy. *Strength & Conditioning Journal* 16: 20-31, 1994.

55. Newton, RU, Murphy, AJ, Humphries, BJ, Wilson, GJ, Kraemer, WJ, & Hakkinen, K. Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. *European Journal Applied Physiology* 75: 333–342, 1997.

56. Nuzzo, JL, McBride, JM, Cormie, P, & McCaulley, GO. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *Journal of Strength and Conditioning Research* 22: 699-707, 2008.

57. Pearson, SN, Cronin, JB, Hume, PA, & Slyfield, D. Kinematics and kinetics of the bench-press and bench-pull exercises in a strength-trained sporting population. *Sports Biomechanics* 8: 245-254, 2009.

58. Pennington, J, Laubach, L, De Marco, G, & Linderman, J. Determining the optimal load for maximal power output for the power clean and snatch in collegiate male football players. *Journal of Exercise Physiology* 13: 10-20, 2010.

59. Romero, S, Vila, H, Ferragut, C, & Alcaraz, PE. Power-strength curve in basketball players. *Revista de Psicología del Deporte*, 18: 425-428, 2009.

60. Sánchez-Medina, L, Pérez, C, & González-Badillo, J. Importance of the propulsive phase in strength assessment. *International Journal of Sports Medicine* 31: 123-129, 2010.

61. Siegel, JA, Gilders, RM, Staron, RS, & Hagerman, FC. Human muscle power output during upper- and lower-body exercises. *Journal of Strength and Conditioning Research* 16: 173-178, 2002.

62. Soriano, MA, Jiménez-Reyes, P, Rhea, MR, & Marín, PJ. The optimal load for maximal power production during lower-body resistance exercises: A meta-analysis. *Sports Medicine* 45:1191-1205, 2015.

63. Stone, MH. Position statement: Explosive exercise and training. *Strength & Conditioning Journal* 15: 7–15, 1993.

64. Stone, MH, O'Bryant, HS, McCoy, L, Coglianese, R, Lehmkuhl, M, & Schilling, B. Power and maximum strength relationships during performance of dynamic and static weighted jumps. *Journal of Strength and Conditioning Research* 17: 140-147, 2003.

65. Stone, MH, Sanborn, K, O'Bryant, HS, Hartman, M, Stone, ME, Proulx, C, Ward, B, & Hruby, J. Maximum strength-power-performance relationships in collegiate throwers. *Journal of Strength and Conditioning Research* 17: 739-745, 2003.

66. Suchomel, TJ, Comfort, P, & Stone, MH. Weightlifting pulling derivatives: Rationale for implementation and application. *Sports Medicine* 45: 823-839, 2015.

67. Thomas, GA, Kraemer, WJ, Spiering, BA, Volek, JS, Anderson, JM, & Maresh, CM. Maximal power at different percentages of one repetition maximum: influence of resistance and gender. *Journal of Strength and Conditioning Research* 21: 336-342, 2007.

68. Tihany, J. (1989). Fisiología mecánica de la fuerza. *Revista de Entrenamiento Deportivo* 3: 2-10, 1989.

69. Toji, H, Kensasu, S, & Kaneko, M. Effects of combined training loads on relations among force, velocity and power development. *Canadian Journal of Applied Physiology* 22: 328–336, 1997.

70. Turner, AP, Unholz, C. Potts, N, & Coleman, SG. Peak power, force, and velocity during jump squats in professional rugby players. *Journal of Strength and Conditioning Research* 26: 1594-600, 2012.

71. Winchester, JB, Erickson, TM, Blaak, JB, & McBride, JM. Changes in bar path kinematics and kinetics after power-clean training. *Journal of Strength and Conditioning Research* 19: 177-183, 2005.

72. Zatsiorsky, VM, & Kraemer, WJ. Science and practice of strength training. Champaign, IL: *Human Kinetics*, 2006