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Potential Benefits and Rationale to Implement Weightlifting Overhead Pressing Derivatives in Strength and Conditioning Programmes for Athletic Development

Beneficios Potenciales y Fundamentación de la Implementación de Ejercicios de Empuje Vertical Derivados de la Halterofilia en Programas de Fuerza y Acondicionamiento Físico para el Desarrollo Deportivo

D. Marcos Antonio Soriano Rodríguez

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POTENTIAL BENEFITS AND RATIONALE TO IMPLEMENT WEIGHTLIFTING OVERHEAD PRESSING DERIVATIVES IN STRENGTH AND CONDITIONING PROGRAMMES FOR ATHLETIC DEVELOPMENT

BENEFICIOS POTENCIALES Y FUNDAMENTACIÓN DE LA IMPLEMENTACIÓN DE EJERCICIOS DE EMPUJE VERTICAL DERIVADOS DE LA HALTEROFILIA EN PROGRAMAS DE FUERZA Y ACONDICIONAMIENTO FÍSICO PARA EL DESARROLLO DEPORTIVO

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Doctora por la Universidad de Murcia y Profesora Titular del Departamento de Actividad Física y Deporte de la Universidad de Murcia

AUTORIZA:

La presentación de la tesis doctoral titulada: **"POTENTIAL BENEFITS AND RATIONALE TO IMPLEMENT WEIGHTLIFTING OVERHEAD PRESSING DERIVATIVES IN STRENGTH AND CONDITIONING PROGRAMMES FOR ATHLETIC DEVELOPMENT" (BENEFICIOS POTENCIALES Y FUNDAMENTACIÓN DE LA IMPLEMENTACIÓN DE EJERCICIOS DE EMPUJE VERTICAL DERIVADOS DE LA HALTEROFILIA EN PROGRAMAS DE FUERZA Y ACONDICIONAMIENTO FÍSICO PARA EL DESARROLLO DEPORTIVO)**, realizada por **D. Marcos Antonio Soriano Rodríguez**, bajo mi inmediata dirección y supervisión, y que presenta para la obtención del Grado de Doctor por la Universidad de Murcia.

Y, para que surta los efectos oportunos al interesado, firmo la presente en Murcia, a seis de mayo de dos mil veinte.

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D. Pedro Jesús Marín Cabezuelo

This thesis is dedicated to weightlifting lovers, researchers, coaches and lifters who have devoted their lives to this sport.

"*I can tell you everything I know about weightlifting in 10 minutes, then it will take you 10 years to understand* ***what I said"*** Coach Joe mills

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Table of Contents

List of figures

List of tables

Abbreviations

1RM: one repetition maximum

ANOVA: analysis of variance

BM: body mass

C&J: clean and jerk

CF: CrossFit® athletes

CIs: confidence intervals

CM: centre of mass

CSCS: Certified Strength and Conditioning Specialist

CV: coefficient variation

EMG: electromyography

F_{max}: maximal force

ICC: intraclass correlation coefficient

IMTP: isometric mid-thigh pull

JCR: journal citation reports

M: male

MX: mixed group of athletes

NSCA: National Strength and Conditioning Association

PJ: push jerk

P_{max}: maximal power

PP: push press

Q: quartile

RFD: rate of force development

S&C: strength and conditioning

SDD: smallest detectable difference

SEM: standard error measurement

SJ: split jerk

SSC: stretch-shortening cycle

V_{max}: maximal velocity

WL: weightlifters

WOPD: weightlifting overhead pressing derivatives

List of Appendixes

Abstract

The aim of this series of studies was to determine the potential benefits and rationale to implement WOPD in S&C programmes for athletic development.

Study 1: The findings from this review demonstrated that WOPD utilized in S&C programmes, such as the PP, PJ, and SJ may provide an adequate stimulus to improve not only weightlifting performance but also sports performance. These findings were based on a review of 13 studies focused on the kinetic and kinematic mechanisms underpinning WOPD. The potential benefits are that I) the use of WOPD is an additional strategy to improve weightlifting performance; II) WOPD require the ability to develop high forces rapidly by an impulsive triple extension of the hips, knees and plantar flexion of the ankles, which is mechanically similar to many sporting tasks; III) WOPD may be beneficial for enhancing power development and maximal strength in the sport population, and, finally, IV) WOPD may provide a variation in training stimulus for the sports population due to the technical demands, need for balance and coordination.

The results of study 2 demonstrated that in the case of WOPD, practitioners and researchers may simplify the 1RM single procedure for a given exercise by performing the 1RM during the three main WOPD (PP, PJ and SJ) in sequence, in one testing session (combined assessment method), with no significant ($p > 0.05$) or meaningful ($\eta^2 \leq 0.001$) differences between the single (testing each on separate days) and the combined assessment method. Moreover, there was a high reliability, low variability, and low measurement error for the PP (ICC = 0.960; CV = 1.8%; SDD = 7.1%), PJ (ICC = 0.978; CV = 1.5%; SDD = 5.4%) and SJ (ICC = 0.987; CV = 1.2 %; SDD = 4.6%) in the combined assessment.

The results of study 3 demonstrated that in a comparison of the 1RM performance for the three main WOPD (PP, PJ and SJ) among three sport groups (weightlifters, CrossFit®

athletes, and a mixed group of athletes) there was a significant ($p < 0.001$) main effect of exercise ($\eta^2 = 0.101$) and exercise x group interaction ($\eta^2 = 0.012$) on the 1RM performance, while there was no statistical significance ($p = 0.175$) for the effect of group ($\eta^2 = 0.066$). The results of this study provided evidence that exercise selection impacts the 1RM performance. Furthermore, in the interaction of exercise and sport group, weightlifters demonstrated significantly higher 1RM SJ performance (115.3 ± 21.2 kg) compared to the PJ (105.5 ± 17.9 kg; $p < 0.001$) and PP (94.7 ± 17.6 kg; $p < 0.001$). The CrossFit® group demonstrated significantly higher 1RM SJ performance (96.6 ± 16.3 kg) compared to the PP (86.1 ± 13.8 kg; $p < 0.001$), but not significantly compared to the PJ (93.0 ± 14.0 kg; $p = 0.90$). Similarly, the mixed group of athletes demonstrated significantly higher 1RM SJ performance (102.9 ± 18.3 kg) compared to the PP (90.4 ± 14.8 kg; $p < 0.001$), but not significantly greater than the PJ (97.1 ± 17.4 kg; $p = 0.110$). These findings provided an insight of the importance of training specificity, where weightlifters reported the largest differences in 1RM performance between exercises (9-22%) in comparison to the CrossFit® (4-11%) and a mixed group of athletes (6-14%).

This thesis is the first work focused on the potential benefits and rationale for the implementation of WOPD in S&C programmes for athletic development. Further research on the kinetic and kinematic mechanisms of the main WOPD, across loads, in sporting populations, is guaranteed to include a better understanding of the topic along with the longitudinal training effects and adaptations.

Resumen

Los ejercicios que engloban el deporte de la halterofilia, la arrancada y el dos tiempos (cargada y envión), destacan por ser ejercicios multi-articulares, técnicamente complejos, que engloban el movimiento de todo el sistema músculo-esquelético de manera coordinada y secuencial. Estos ejercicios requieren al levantador realizar acciones musculares de alta intensidad que resultan en una gran generación de fuerza absoluta, fuerza en la unidad de tiempo, e impulso, con el fin de acelerar la barra, dando lugar a una gran generación de potencia muscular. De este modo, los ejercicios de halterofilia son a menudo incluidos en programas de fuerza y acondicionamiento físico como herramientas efectivas para el desarrollo de la fuerza máxima y potencia en deportistas de otras disciplinas.

Los ejercicios de halterofilia son divididos en función de sus derivaciones en tirones, cargadas y arrancadas de fuerza, y ejercicios de empuje vertical. Estas derivaciones son más utilizadas que los movimientos completos (arrancada y dos tiempos), ya que requieren de un menor dominio técnico que facilita el proceso de aprendizaje y adquisición de una ejecución correcta por parte de los deportistas. Los ejercicios derivados de la halterofilia incluidos en la clasificación de los tirones y cargadas (por ejemplo: tirón de arrancada, tirón de cargada colgante, arrancada de fuerza, cargada fuerza colgante) han sido bien estudiados en la literatura, así como su contribución al desarrollo de la fuerza y potencia muscular en los deportistas. Sin embargo, existe poca información acerca de los ejercicios principales de empuje vertical, habiendo una falta de fundamentación en su implementación y aplicación en programas de fuerza y acondicionamiento físico.

La necesidad de resolver esta cuestión dentro de esta área de conocimiento ha sido la principal razón para la elección de este tópico como tesis doctoral. La presente tesis por compendio de publicaciones pretende proporcionar información acerca de los beneficios potenciales y la fundamentación de la implementación de ejercicios de empuje vertical

derivados de la halterofilia (WOPD) en programas de fuerza y acondicionamiento físico para el desarrollo deportivo. La elección de la presente tesis doctoral como compendio de publicaciones está basada en la necesidad de proporcionar diferentes respuestas, a preguntas diferentes, pero a la vez relacionadas, una a una, como resultado de un área de conocimiento fascinante que está aún por explorar. Este ha sido el primer trabajo que se ha centrado en la utilización de los WOPD que no solo cubre sus beneficios potenciales sobre el rendimiento del deporte de la halterofilia, sino que también discute y fundamenta la aplicación de los WOPD para la mejora del rendimiento deportivo en deportistas no halterófilos.

En el estudio 1 se realizó una revisión narrativa con el objetivo de obtener evidencia empírica, para proporcionar una visión sobre las variables cinéticas y cinemáticas, de los mecanismos subyacentes a los WOPD y la fundamentación para su aplicación e implementación en programas de fuerza y acondicionamiento físico, para la consecución de un mayor rendimiento deportivo. Para ello se realizó una búsqueda en bases de datos electrónicas (PubMed, Medline [EBSCO] y Google Scholar) para identificar todas las publicaciones sobre los WOPD. Como criterios de inclusión se utilizaron: I) artículos científicos a texto completo que hayan explorado y analizado los WOPD y II) artículos científicos que hayan proporcionado información acerca de variables cinéticas y cinemáticas de los ejercicios. Un total de 13 estudios fueron identificados para el PP, PJ y SJ.

Los hallazgos de esta revisión de la literatura científica revelan que la utilización e implementación de los principales WOPD (PP, PJ y SJ) puede proporcionar un estímulo adecuado para mejorar no solo el rendimiento en el deporte de la halterofilia, sino que también el rendimiento deportivo en deportistas no halterófilos por diferentes razones. I) La aplicación de los WOPD es una estrategia bien documentada y útil para la mejora del rendimiento en el deporte de la halterofilia, debido al alto número de intentos fallidos en la fase del envión en competiciones. II) Los WOPD requieren de la habilidad para desarrollar fuerza rápidamente a través de la cadena cinética cerrada de las extremidades inferiores, que es mecánicamente similar a muchas acciones deportivas. III) Este patrón de movimiento desarrolla una potente triple extensión de la articulación de la cadera, rodilla y flexión plantar de los tobillos, así como optimiza el control motor y la coordinación dado el rol clave de las extremidades inferiores y el tronco en la estabilización y la transmisión de fuerzas en dicho patrón. IV) Los WOPD pueden ser beneficiosos para mejorar el desarrollo de potencia y fuerza máxima en deportistas de diferentes disciplinas. Esto ha sido documentado en la literatura científica dada la evidencia de que los WOPD desarrollan altos picos de fuerza, altos desarrollos de fuerza en la unidad de tiempo, resultando finalmente en niveles de desarrollo de potencia altos, principalmente debido a que estos ejercicios tienen la propiedad de que cargas pesadas pueden ser levantadas a velocidades de movimiento relativamente altas.

El estudio 2 tuvo un diseño transversal y se basó en la definición de un protocolo novedoso para la evaluación de la fuerza máxima dinámica. Como breve introducción, la fuerza muscular destaca como un determinante clave del rendimiento deportivo, y como tal, evaluar de manera precisa la fuerza muscular es una parte crucial de cualquier programa de acondicionamiento físico. El test de la 1RM ha sido el método preferido para la evaluación de la fuerza dinámica máxima, dada su alta fiabilidad y validez. Además, otra aplicación es que los resultados obtenidos en el test de la 1RM pueden ser usados para prescribir cargas de entrenamiento basadas en porcentajes de la 1RM. Sin embargo, la mayoría de investigaciones se han centrado principalmente en la evaluación de tres ejercicios, el press de banca, la sentadilla y la cargada de fuerza. A la fecha, existe una falta de información sobre el rendimiento de la 1RM en otros ejercicios como los WOPD (PP, PJ y SJ), así como de valores de fiabilidad y variación en la medición, que no han sido investigados para estos ejercicios. Además, como no es eficiente en la temporalización el realizar cada test de 1RM en días separados, el objetivo de este presente estudio fue determinar la validez de realizar la evaluación de la 1RM para los tres ejercicios (PP, PJ y SJ) en un orden secuencial, en una única sesión de entrenamiento (método de evaluación combinado) y realizar una comparación con su método criterio (la evaluación de cada ejercicio realizada en días separados), al tiempo que se determina la fiabilidad entre sesiones del método combinado.

Veintidós hombres (edad: 28.5 ± 1.3 años; altura: 1.80 ± 0.1 m; masa corporal: 84.9 ± 1.9 kg; experiencia de entrenamiento de fuerza: 4.3 ± 4.1 años) entrenados y familiarizados con los WOPD y la evaluación de la 1RM, competidores actuales a nivel regional y nacional en halterofilia, CrossFit® y otros deportes, desarrollaron dos sesiones de evaluación de la 1RM mediante el método combinado y tres sesiones de evaluación de la 1RM de manera separada en cada ejercicio (en días diferentes). Todos los sujetos fueron testeados en un total de 5 sesiones (2 para el método de evaluación combinado y 3 para la evaluación de cada ejercicio por separado), en orden aleatorizado, donde cada test tuvo una separación de 4-5 días, y todo este proceso se realizó en un periodo máximo de 4 semanas. Todos los test fueron desarrollados usando barras y discos (Werksan weights and Olympic bar; Werksan, Moorestown, New Jersey, USA), además de plataformas de levantamiento y jaulas de fuerza (Powerlift, Iowa, USA). En resumen, un total de 9 test de 1RM fueron evaluados, tres para cada ejercicio (dos para el método de evaluación combinado y uno para la evaluación de cada ejercicio por separado). Esta investigación fue aprobada por la Junta de Revisión Institucional de la Universidad de Salford (Manchester, Reino Unido) (*Appendix I*), y todos los sujetos proporcionaron su consentimiento informado antes de la participación en cada estudio (*Appendix II*). Este estudio se realizó conforme a los principios del "*World Medical Association´s Declaration of Helsinki*".

La fiabilidad se evaluó mediante el coeficiente de correlación intraclase (ICC), coeficiente de variación (CV) y los intervalos de confianza (CIs) asociados al 95%. El error estándar de medida (SEM) y la mínima diferencia detectable (SDD) fueron calculados para establecer los errores de medición aleatorios. Se utilizó un análisis de varianza (ANOVA) de medidas repetidas para cada ejercicio (PP, PJ y SJ) con la corrección de Bonferroni *post hoc*, que fue utilizada para determinar las diferencias en el rendimiento de la 1RM para los dos métodos de evaluación combinados y el método de evaluación de cada ejercicio por separado. Además, se implementaron diagramas de Bland-Altman para determinar y clarificar el acuerdo entre ambos métodos para cada ejercicio. Los resultados revelaron una alta fiabilidad, baja variabilidad y bajo error de medición para el ejercicio PP (ICC con el 95% CIs = 0.960 [0.907-0.983]; CV con el 95% CIs = 1.8% [1.2-2.6]; SDD = 7.1%), PJ (ICC con el 95% CIs = 0.978 [0.949-0.991]; CV con el 95% CIs = 1.5% [0.7-2.0]; SDD = 5.4%) y SJ (ICC = 0.987 [0.969-0.995]; CV con el 95% CIs = 1.2% [0.6-1.8]; SDD = 4.6%). Además, no hubo diferencias estadísticamente significativas ($p > 0.05$; $\eta^2 \leq 0.001$) entre el método de evaluación combinado y la evaluación de cada ejercicio por separado. Por último, los diagramas de Bland-Altman mostraron un acuerdo muy alto, sin sesgos sistemáticos, y errores aleatorios bajos entre el método de evaluación combinado y la evaluación de cada ejercicio por separado, en los tres ejercicios analizados.

Los hallazgos de este estudio determinaron que la alta validez y acuerdo del método de evaluación combinado con la evaluación de cada ejercicio por separado, sugiere que entrenadores e investigadores pueden simplificar el procedimiento de los test, evaluando la 1RM en los principales WOPD (PP, PJ y SJ), en orden secuencial, en una única sesión y no encontrar diferencias significativas; además, el método de evaluación combinado demuestra una alta fiabilidad, baja variabilidad, y un bajo error de medición.

El estudio 3, tuvo un diseño transversal donde se continuó profundizando en la evaluación de la fuerza máxima dinámica, mediante el test de 1RM en los principales WOPD (PP, PJ y SJ9, para tres grupos deportivos diferentes (halterófilos, practicantes de CrossFit®, y un grupo mixto de deportistas). Además, se exploraron las diferencias en el rendimiento de la 1RM de estos WOPD en función del grupo deportivo, estudiando así la posible influencia que el factor grupo deportivo pudiera tener sobre el rendimiento.

Cuarenta y seis hombres (edad: 28.8 ± 6.4 años; altura: 1.8 ± 0.6 m; masa corporal: 84.1 ± 10.2 kg; experiencia con ejercicios de halterofilia: 3.6 ± 3.1 años) entrenados participaron en este estudio. Los tres grupos deportivos constaban de participantes que competían a nivel regional y nacional en sus respectivas disciplinas, estos grupos se dividieron en un grupo de 15 halterófilos (edad: 26.4 ± 1.6 años; altura: 1.8 ± 0.2 m; masa corporal: 81.1 ± 3.1 kg; experiencia con ejercicios de halterofilia: 4.5 ± 1.3 años), un grupo de 19 practicantes de CrossFit® (edad: 32.1 ± 1.1 años; altura: 1.8 ± 0.1 m; masa corporal: 83.4 ± 2.0 kg; experiencia con ejercicios de halterofilia: 3.3 ± 0.3 años) y un grupo mixto de deportistas de diferentes disciplinas como el rugby, la natación, el voleibol o el atletismo (edad: 26.2 ± 2.1 años; altura: 1.8 ± 0.1 m; masa corporal: 88.9 ± 2.5 kg; experiencia con ejercicios de halterofilia: 3.2 ± 0.6 años). El rendimiento de la 1RM para cada ejercicio (PP, PJ y SJ) se obtuvo mediante la realización del método de evaluación combinado. En dicho método, la evaluación del rendimiento de la 1RM en PP, PJ y SJ se desarrolló en una única sesión de evaluación y en orden secuencial. Todos los test fueron desarrollados usando barras y discos (Werksan weights and Olympic bar; Werksan, Moorestown, New Jersey, USA), además de plataformas de levantamiento y jaulas de fuerza (Powerlift, Iowa, USA). Esta investigación fue aprobada por la Junta de Revisión Institucional de la Universidad de Salford (Manchester, Reino Unido) (Appendix I), y todos los sujetos proporcionaron su consentimiento informado antes de la participación en cada estudio (Appendix II). Este estudio se realizó conforme a los principios del "*World Medical Association´s Declaration of Helsinki*".

Se utilizó un ANOVA mixto de medidas repetidas con la corrección Bonferroni *post hoc*, para evaluar las diferencias en el rendimiento de la 1RM entre ejercicios (PP, PJ y SJ) como factor intra-sujeto y grupo deportivo (halterófilos, practicantes de CrossFit® y grupo mixto de deportistas) como factor inter-sujeto. Los resultados del ANOVA revelaron un efecto estadísticamente significativo del factor ejercicio ($p < 0.001$; $\eta^2 = 0.101$) y de la interacción ejercicio y grupo deportivo ($p < 0.001$; $\eta^2 = 0.012$), sobre el rendimiento de la 1RM. Sin embargo, no hubo diferencias estadísticamente significativas entre grupos ($p = 0.175$; $\eta^2 = 0.066$) con una potencia estadística de 0.918. El grupo de halterófilos demostró un mayor rendimiento estadísticamente significativo de la 1RM en SJ (115.3 ± 21.2 kg) en comparación con el PJ (105.5 ± 17.9 kg; $p < 0.001$) y el PP (94.7 ± 17.6 kg; $p < 0.001$). El grupo de practicantes de CrossFit® demostró un mayor rendimiento estadísticamente significativo de la 1RM en el SJ (96.6 ± 16.3 kg) en comparación con el PP (86.1 ± 13.8 kg; $p < 0.001$), pero este no fue significativamente superior en comparación con el PJ (93.0 ± 14.0 kg; $p = 0.90$). El grupo mixto de deportistas mostró un mayor rendimiento estadísticamente significativo de la 1RM en SJ (102.9 ± 18.3 kg) en comparación con el PP (90.4 ± 14.8 kg; $p < 0.001$), pero este no fue significativamente superior en comparación con el PJ (97.1 ± 17.4 kg; $p = 0.110$).

Los hallazgos de este estudio muestran que i) la selección de ejercicios influye en el rendimiento de la 1RM. Siendo el SJ el ejercicio donde mayores cargas son levantadas, y por tanto, mayores niveles de fuerza máxima dinámica son expresados; seguido del PJ y finalmente el PP. Por lo tanto, será necesario desde el punto de vista práctico seguir esta secuencia cuando el objetivo del entrenamiento sea desarrollar la fuerza máxima, para alcanzar un mayor desarrollo y rendimiento deportivo. Además, se demostró que ii) existe un efecto de interacción del ejercicio y el grupo deportivo causado por las diferencias más altas en el rendimiento de la 1RM entre ejercicios de los halterófilos experimentados en comparación con los practicantes de CrossFit® y el grupo mixto de deportistas. Consecuentemente, los hallazgos de este estudio proporcionan evidencia sobre la importancia de la especificidad del entrenamiento, donde los profesionales del ejercicio y la preparación física deberían ser conscientes de las diferencias existentes entre ejercicios, grupo deportivo y la interacción de estos factores, con el fin de prescribir las cargas adecuadamente, para obtener un mayor desarrollo y rendimiento deportivo. Por ejemplo, cuando el principal objetivo del entrenamiento sea el desarrollo de la fuerza máxima, los halterófilos experimentados requieren del uso del SJ sobre el PJ y el PP. Sin embargo, para los practicantes de CrossFit® así como el grupo mixto de deportistas, el PJ y el SJ pueden ser usados indistintamente sobre el PP.

Esta tesis ha sido el primer trabajo que se ha centrado en los beneficios potenciales y la fundamentación de implementar los WOPD en programas de fuerza y acondicionamiento físico para el desarrollo deportivo. Es necesaria más investigación sobre los mecanismos cinéticos y cinemáticos de los principales WOPD (PP, PJ y SJ), con diferentes cargas (intensidades), aplicados en deportistas no halterófilos, con el fin de obtener un mayor entendimiento sobre esta área de conocimiento, así como los efectos y adaptaciones longitudinales de estos ejercicios.

CHAPTER 1

JUSTIFICATION

Justification

Strength and muscular power are considered critical factors of dynamic athletic performance (1,2). The development of higher power outputs and maximal strength levels along with the ability to express high rates of force development (RFD) have been related to a higher performance in many sporting events (e.g. sprinting, jumping, tackling, changing of direction) (2–8). Additionally, there is strong evidence that higher levels of muscular strength and power may enhance the economy and efficiency of endurance-based sports (e.g. swimming, cycling, canoeing) (9–16). Researchers and practitioners have as crucial goals to increase the strength levels and the ability of the athlete to exert maximal power outputs during the different sporting tasks (2,17–19).

Resistance training is a preferred option to develop general strength and power (20–23). There are a variety of methods to increase the maximal strength and power with resistance training programmes including; traditional strength training with heavy-loads and relatively low movement velocity, plyometric and ballistic training with relatively light-loads and relatively high velocities or the use of weightlifting exercises and their derivatives (2,3,17,24,25). Weightlifting exercises and their derivatives are regularly included in S&C as effective training tools to increase maximal strength and power development (24–30). Furthermore, weightlifting movements target the triple extension pattern of the hips, knees and ankles (plantar flexion), which is integral to the successful execution in the majority of the lower-body dynamic athletic tasks such as jumping, sprinting, tackling or changing of direction (26,31–34).

In athletic development, weightlifting derivatives such as the power clean, clean pull, hang high pull and hang power clean are presumably more utilized than the full movements snatch or the clean and jerk (24,25,35–43). The main reason is that weightlifting derivatives are more accessible for practitioners to teach and athletes to master when compared to the full snatch and the C&J due to the differences in the catch position (24,44–47). Besides, many researchers have investigated and determined that weightlifting derivatives may be beneficial for achieving high levels of power outputs and enhance sports performance in most athletic tasks (24,25,34,36,37). The majority of researchers have focused on the catching and pulling derivatives, due to growing evidence based findings which suggest that weightlifting pulling and catching derivatives as useful training tools to overload the triple extension pattern generating high peak forces, RFD and power outputs under loading conditions (36–39,42,44,48). However, less attention has been paid to other weightlifting derivatives as the PP, PJ or SJ.

The need for bridging this gap in the scientific literature is the main reason for the election of this topic for a doctoral thesis. The present thesis by a compendium of publications aims to provide information regarding potential benefits and rationale to implement WOPD in S&C programmes for athletic development. A summary of the studies' design, methods and main findings of the three studies are presented in Table 1 along with information of the journal, impact factor, ranking in sports science domain, and year of publication. The election of presenting the doctoral thesis as a compendium of publications was based on the need of giving answers to different but related questions, one by one, as a result of an unexplored, yet fascinating topic.

Table 1. A summary of the experimental design, methodology and main findings of the studies included along with the information of the journal of publication.

	Study 1	Study 2	Study 3
Design	Narrative review	A cross-sectional, within- and between-subjects design	A cross sectional, within- and between-subjects design
Journal	*Sports medicine*	*Journal of Strength and Conditioning Research*	*International Journal of Sports physiology and performance*
Year of publication	2019	2020	2020
Impact factor JCR	7.583 (Q1; R: 2)	3.017 (Q1; R: 18)	3.979 (Q1; R: 8)
Objectives	1) Reviewing evidence to provide an insight into the kinetic and kinematic mechanisms underpinning WOPD. 2) Finding the rationale for the application of WOPD to resistance training programs to enhance sports performance	1) Determining the validity of performing the three 1RM assessments for the PP, PJ, and SJ in sequence in one testing session (1RM combined assessment method) vs. the criterion method (1RM single assessment) on separate days 2) Determining the between-session reliability of the 1RM combined assessment method	1) Comparing the 1RM performance between PP, PJ and SJ. 2) Exploring the differences of the 1RM performances between WL, CF and MX

Methods	A literature search of electronic databases (PubMed, Medline [EBSCO] and Google Scholar) to identify all publication on WOPD. As inclusion criteria: a) full text, research articles exploring and analysing WOPD and b) research articles reporting insight into kinetics or kinematics of the exercises	22 M performed two 1RM combined assessment method and three 1RM single assessment for PP, PJ and SJ. Reliability was assessed by the ICC, CV and associated 95% CIs. SEM and SDD were calculated to stablish random error scores. ANOVA of repeated measures with Bonferroni post hoc analysis was performed to determine differences in the 1RM performance for the two 1RM combined assessment methods and the 1RM single assessment for each exercise, over time. Bland-Altman plots were used to determine and clarify the agreement between methods.	46 M (15 WL, 19 CF and 12 MX) performed a 1RM combined assessment method for the PP, PJ and SJ. ANOVA of repeated measures with Bonferroni post hoc analysis was applied using exercise (PP, PJ and SJ) as within-subject factor, and group (WL, CF and MX) as between-subject factor.
Results	13 studies were identified for the press, PP; PJ and SJ. The findings revealed that the use of these exercises may provide an adequate stimulus to improve sport performance due to the high forces, velocities and power outputs developed. Therefore, the potential benefits highlighted in this review provided a justification for the implementation of WOPD in sports training	A high reliability, low variability, and low measurement error were evident for the PP (ICC = 0.960; CV =1.8%; SDD = 7.1%), PJ (ICC = 0.978; CV = 1.5%; SDD = 5.4%) and SJ (ICC = 0.987; CV = 1.2%; SDD = 4.6%). There were no significant ($p > 0.05$) or meaningful ($\eta^2 \leq 0.001$) differences between the single and combined assessments. Bland-Altman plots showed a high agreement, with no systematic bias and low random errors between the single and combined assessment.	There was a significant ($p < 0.001$) main effect of exercise ($\eta^2 = 0.101$) and exercise x group interaction ($\eta^2 = 0.012$) on the 1RM performance, while the main effect ($\eta^2 = 0.066$) of group did not reach statistical significance ($p = 0.175$). WOPD impact the 1RM performance. In addition, WL reported higher differences in the 1RM performance between-exercises compared to CF and MX.

JCR journal citation reports, Q quartile, R ranking in sports science domain (2018), WOPD weightlifting overhead pressing derivatives, PP push press, PJ push jerk, SJ split jerk, 1RM one repetition maximum, M male, ICC intraclass correlation coefficient, CV coefficient variation, CIs confidence intervals, SEM standard error measurement, SDD smallest detectable difference, ANOVA analysis of variance, WL weightlifters CF CrossFit® athletes, MX mixed group of athletes.

CHAPTER 2

OVERVIEW AND PROGRESSION OF STUDIES

Overview and progression of studies

Athletic strength refers to the force generated by the neuromuscular system during sporting activities. Power is the rate of doing work per unit of time or force by velocity of the movement (49). During a long-term structured S&C programme, coaches employ ballistic, plyometrics, traditional resistance exercises or weightlifting exercises and their derivatives as common strategies to develop both general muscular strength and power adaptations for athletic development (20–23).

Weightlifting exercises and their derivatives are complex whole-body movements performed in the sport of weightlifting that requires the lifter to use a series of high-intensity muscular actions that result in high peak forces, RFD, and impulse generated in order to adequately accelerate the barbell, consequently resulting in high power outputs (30,50–53). Weightlifting exercises may be further subdivided into weightlifting catching, pulling and overhead pressing derivatives (24,25,54). Weightlifting exercises and their catching and pulling derivatives (e.g. power clean, hang power snatch, clean pull or mid-thigh clean pull) have been well studied in the literature as well as their contribution to increase athletic performance (24,25,41). However, little information is known about WOPD, having a lack of evidence-based rationale for the implementation and application of these exercises in S&C programmes for athletic development.

2.1 Study 1

Numerous studies have provided information regarding the kinetics and kinematics of weightlifting exercises and their pulling and catching derivatives (24,25,41,55–58). A rationale for the implementation of weightlifting pulling and catching derivatives such as the power clean, hang power clean, hang high pull or mid-thigh clean pull in S&C programmes has also been well-documented (24,25,36). However, little research has been conducted to date regarding the kinematic and kinetic variables of WOPD and their application in structured S&C programmes to enhance the athletic development. Rather, researchers have focused on the technique of different exercises: standing press (59–62), PP (59,63–65), and variations of the jerk (59,66–68). Therefore, the aim of this study was to review empirical evidence to provide an insight into the kinetic and kinematic mechanisms underpinning WOPD and the rationale for the application to resistance training programs to enhance sports performance.

2.1.1 Summary

The findings of study 1 revealed that the most commonly WOPD utilized in S&C programmes are the PP, PJ, and SJ performed from the rack position or behind the neck. The use of these exercises may provide an adequate stimulus to improve not only weightlifting performance but also sports performance as: 1) the use of WOPD is an additional strategy to improve weightlifting performance; 2) WOPD require the ability to develop high forces rapidly by an impulsive triple extension of the hips, knees and plantar flexion of the ankles, which is mechanically similar to many sporting tasks; 3) WOPD may be beneficial for enhancing power development and maximal strength in the sport population, and, finally, 4) WOPD may provide a variation in training stimulus for the sports population due to the technical demands, need for balance and coordination. Therefore, the potential benefits highlighted in this review of the literature provide a justification for the implementation of WOPD such as the PP, PJ and SJ in sports training. However, there is a lack of information regarding the longitudinal training effects that may result from implementing WOPD in structured S&C programmes.

2.2 Study 2

Muscle strength is a key determinant of dynamic athletic performance (19,69–73), and as such, accurate assessment of an individual' muscular strength is crucial as a part of a comprehensive athlete-monitoring plan (49,74). The 1RM during the bench press, squat, and power clean are the preferred and a highly reliable test used by S&C coaches to the assessment of the maximal dynamic strength (49,74,75). Furthermore, the results can be used to prescribe training loads for subsequent phases of training (49,74). However, while the protocols of the 1RM during the bench press, squat or power clean have been standardized and reliability measures have been studied (43,76,77), there is a lack of information regarding the WOPD.

The PP, PJ and SJ are WOPD that are commonly included in the training programs of sporting and fitness populations (59,63,64,78). To date, there is a lack of information regarding the 1RM for the three exercises (PP, PJ and SJ) and reliability has not been reported by researchers. Furthermore, as it is not time efficient to assess each 1RM performance on separate days, with no published equation to predict 1RM performance in one task from another, the aim of this study was to determine the validity of performing the three 1RM assessments for the PP, PJ, and SJ in sequence in one testing session (combined assessment) vs. the criterion method (testing on separate days), while determining the between-session reliability of the combined assessment. It was hypothesized that the measures obtained in the combined assessment (PP, PJ, and SJ in sequence in one session) would show a high agreement respect to the criterion method (1RM single assessment). It was also hypothesized that the combined assessment of the PP, PJ, and SJ 1RM would exhibit a high reliability.

2.2.1 Summary

The findings of study 2 revealed that high reliability, low variability, and low measurement error were evident for the PP (ICC and associated CIs = 0.960 [0.907-0.983]); CV and associated CIs = 1.8% [1.2-2.6]; SDD = 7.1%), PJ (ICC and associated CIs = 0.978 [0.949-0.991]; CV and associated CIs= 1.5% [0.7-2.0]; SDD = 5.4%) and SJ (ICC = 0.987 [0.969-0.995]; CV and associated CIs = 1.2% [0.6-1.8]; SDD = 4.6%). In addition, there were no significant ($p > 0.05$) or meaningful ($\eta^2 \leq 0.001$) differences between the single and combined assessments. The high validity and agreement between the combined assessment and the single testing session suggest that practitioners and researchers may simplify the testing procedure by assessing the 1RM during the three main WOPD in a single testing session. In addition, the results of this study highlight that the 1RM PP, PJ, and SJ are highly reliable for trained lifters that S&C coaches should look for changes greater than 7.1, 5.4, and 4.6% for the PP, PJ, and SJ, respectively. Any given change placed below these thresholds may be considered as part of the measurement error.

2.3 Study 3

Researchers currently suggest that greater muscular strength underpins many physical and performance attributes and can be vastly influential in the ability to generate high RFD and high levels of power (69,70). The 1RM is considered the gold standard for assessing the maximal strength during dynamic tasks (49,75). The 1RM is frequently assessed by S&C professionals to compare the strength between sports and to monitor the changes in strength over time; however, only a few exercises such as the bench press, squat and power clean are commonly reported (74,77,79–81).

Apart from the well-known bench press, power clean and squat, researchers have suggested potential benefits for implementing WOPD as training tools to improve not only weightlifting performance, but also to enhance sports performance (78). Notably, researchers have provided evidence that these exercises may be a time-effective method of enhancing lower-body strength and power (78,82). Therefore, the assessment of 1RM performance of different overhead pressing variations may provide valuable information to practitioners. To date, researchers have not compared the differences in the 1RM performance between the main WOPD as the PP, PJ, and SJ.

Furthermore, it is important to note that researchers have not compared the 1RM performance of the main WOPD between athletes of different sporting backgrounds. Therefore, the main aim of this study was to compare the 1RM performance between three variations of the WOPD (PP, PJ and SJ) for three different sport populations (weightlifters, CrossFit® athletes and a mixed group of athletes). A further aim of the study was to explore the differences in the 1RM performance of these variations across the three sport populations. Based on the evidence that the greatest force, velocity and power occur during the SJ (51), it was hypothesized that, regardless of the sport population, the 1RM performance would be ranked from the highest to the lowest as follows: SJ, PJ and PP variation. Due to the higher predominance of WOPD in weightlifters' training routines, it was also hypothesized that weightlifters would present the highest 1RM for these exercises.

2.3.1 Summary

The findings of study 3 revealed that there was a significant ($p < 0.001$) main effect of exercise ($\eta^2 = 0.101$) and exercise x group interaction ($\eta^2 = 0.012$) on the 1RM performance, while the main effect of group ($\eta^2 = 0.066$) did not reach statistical significance ($p = 0.175$). This study provides evidence that exercise selection impacts the 1RM performance. In addition, the interaction of exercise and sport group was caused by the higher differences in the 1RM performance between-exercises for weightlifters compared to CrossFit® and a mixed group of athletes. Weightlifters demonstrated significantly higher 1RM SJ performance (115.3 ± 21.2 kg) compared to the PJ (105.5 ± 17.9 kg; $p < 0.001$) and PP (94.7 ± 17.6 kg; $p < 0.001$). The CrossFit® group demonstrated significantly higher 1RM SJ performance (96.6 ± 16.3 kg) compared to the PP (86.1 ± 13.8 kg; $p < 0.001$), but not significant than the PJ (93.0 ± 14.0 kg; $p=0.90$). Similarly, the mixed group of athletes demonstrated significantly higher 1RM SJ performance (102.9 ± 18.3 kg) compared to the PP (90.4 ± 14.8 kg; $p < 0.001$), but not significantly greater than the PJ (97.1 ± 17.4 kg; $p = 0.110$). These findings provide an insight of the importance of training specificity, where weightlifters reported the largest differences in 1RM performance between exercises (9-22%) in comparison to the CrossFit® (4-11%) and a mixed group of athletes (6-14%).

2.4 Conclusions

It appears that the use of the main WOPD (PP, PJ, and SJ) may provide an adequate stimulus to improve not only weightlifting performance but also sports performance. Basically, WOPD target the triple extension of the hips, knees and plantar flexion of the ankles, having mechanical similarities to many sporting tasks. Furthermore, PP, PJ and SJ may be beneficial for enhancing power development and maximal strength in the sport population as heavy-loads can be lifted at relatively high movement velocities. In addition, WOPD may provide a variation in training stimulus for the sports population due to the technical demands, the need for motor control and coordination, and the ability required to develop force rapidly through a closed kinetic chain. Therefore, these potential benefits provide a justification for the implementation of WOPD in structured long-term S&C programmes for athletic development.

For the assessment of maximal dynamic strength, performing the 1RM during the PP, PJ and SJ demonstrates a high reliability, low variability, and low measurement error. Furthermore, these exercises may be performed in sequence, in one testing session (PP-PJ-SJ; combined assessment method) and no significant or meaningful differences have been reported in comparison to performing a single assessment method (PP, PJ or SJ separately). The high validity and reliability of the combined assessment suggest that practitioners and researchers may simplify the testing procedure by assessing the 1RM during the three main WOPD (PP, PJ, and SJ) in a single testing session.

The exercise selection of the main WOPD impacts the 1RM performance. The SJ is presumably the exercise where the largest loads are lifted, followed by the PJ and finally, the PP. In addition, there is an interaction effect of exercise and sport group caused by the higher differences in the 1RM performance between-exercises for skilled weightlifters compared to CrossFit® and a mixed group of athletes. These findings provide an insight of the importance of training specificity, where weightlifters reported the largest differences in 1RM performance between exercises (9-22%) in comparison to the CrossFit® (4-11%) and a mixed group of athletes (6-14%).

CHAPTER 3

BACKGROUND

Background

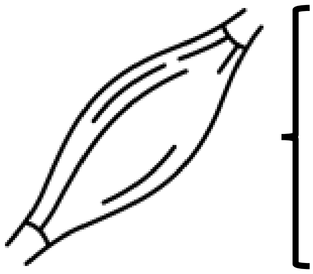
3.1 Terminology

Muscular strength and power refer to the forces generated by the neuromuscular system (49). From the very beginning, it has not been a clear consensus among researchers in what is the appropriate definition of muscular strength and power in sports sciences (83,84). For example, Steindler et al. (85) in 1936 defined strength as "*the maximum display of power*", which used both terms interchangeably, resulting in misuse of the real meaning of both; Muller et al. (86) in 1970 indicated a more mechanical-based definition of muscular strength "*maximum force that can be exerted against an immovable resistance by a single contraction*", however, this definition might seem too simplistic that did not differentiated between isometric or dynamic muscular strength. Later, a more scientifically proven definition of muscular strength was accepted: "*the ability to produce force against an external object or resistance*" and/or "*the ability of the neuromuscular system to produce force*" (87). This definition covers the mechanical concept as it essentially makes strength and mechanical force synonymous, removes some limitations imposed in previous definitions, and allows a further use of the term under different mechanical conditions. However, still a great controversy is found in the literature and S&C suites with some terms being misused systematically by researchers and practitioners (83,84,88). For example, the terms "explosive force", "explosive power", and "explosive strength" are frequently used (89–94), yet criticized under questionable biomechanical and physiological misconceptions (83,84,88). For the sake of clarity, only biomechanical (e.g. force, velocity, power, etc.) and physiological conceptions (e.g. muscular strength, muscular power, etc.) will be used through this document.

3.2 Importance of muscular strength and power for athletic performance

Muscular strength may be expressed by the neuromuscular system in concentric, eccentric or isometric contractions, as well as actions involving the combination of eccentric, isometric and concentric contractions (SSC) (95,96). The highest expression of force during a given task is known as the maximal or maximum strength (75). Maximal strength may be evaluated during static (commonly referred as isometric strength) and dynamic (commonly measured as the 1RM of a given exercise) conditions in athletes (49,75,97,98). Besides, dynamic and isometric strength have been related in the scientific literature to many sporting tasks such as sprinting, changing of direction or jumping. For example: West et al. (99) found significant inverse correlations between the force developed at 100 milliseconds during the isometric mid-thigh pull (IMTP) and the 10-m sprint time test ($r = -0.54$, $p < 0.01$). Similarly, McBride et al. (72) found significant inverse correlations between the maximal dynamic strength (measured as the 1RM during the squat exercise), 40 ($r = -0.605$, $p = 0.010$) and 10 yards ($r = -0.544$, $p = 0.024$). Furthermore, in the same study subjects where subdivided into stronger (> 2.10 1RM/BM) and weaker (< 1.90 1RM/BM) and authors reported significant lower sprint times for the stronger group compared to the weaker group. In addition, isometric and dynamic strength have been well correlated to each other, where de Witt et al. (100) reported high correlations between the peak force during the IMTP and the 1RM during the deadlift ($r = 0.88$, $p \leq 0.05$). Taking these results into account, one may expect that high levels of maximal strength (isometric and/or dynamic) may be closely related to the application of the large forces required in many sporting tasks (70).

Athletes need to exert force against gravity in order to manipulate their own BM (e.g. sprinting, gymnastics, jumping, changing of direction), manipulate their own BM plus an opponents' BM (e.g. tackling, wrestling, pushing), and manipulate an implement (e.g. lifting, throwing, kicking) (69,79,101). Maximal strength levels (isometric and dynamic) are related to the ability of a given athlete to exert force. Similarly, muscular power which can be mechanically defined as the rate of doing work or force exerted multiplied by the velocity of the movement is considered a key factor of dynamic athletic performance; where the ability to generate higher levels of power outputs are related to higher performance in sporting events (1,2,70,102) (Figure 1).



Power = Work/time

= Force x Distance/Time

= Force x Velocity

Figure 1. Mechanical definition of muscular power.

Since power is the product of force and velocity, it seems logical for S&C coaches to target the development of maximal levels of force and velocity for achieving the highest neuromuscular performance of a given athlete (83,84,103). However, during dynamic muscle contractions, as the velocity of shortening increases, the force that a muscle can produce decreases resulting in the well-known inverse relationship of the force-velocity curve. Therefore, the maximal power (P_{max}) will be achieved at compromised levels (submaximal) of the maximal force (F_{max}) and velocity (V_{max}), represented in the force-velocity curve (2,3,103,104). The inverse force-velocity relationship is inherent to the nature of the contracting muscle (105); however, it shows a different behavior depending on the type of muscles and joints involved in the task. For example, it can be seen a hyperbolic force-velocity relationship, with a resultant power-force pattern skewed towards lower forces during isolated muscular fibres and single-joint tasks, where the maximum power is achieved approximately at 30% of the maximal isometric strength (Figure 2A) (2,103,106,107). However, when multi-joint dynamic tasks are performed it may be seen a quasi-linear force-velocity relationship with a resultant power-force pattern revealing the need of higher values of exerted forces to achieve the maximal power production (Figure 2B (108–112)).

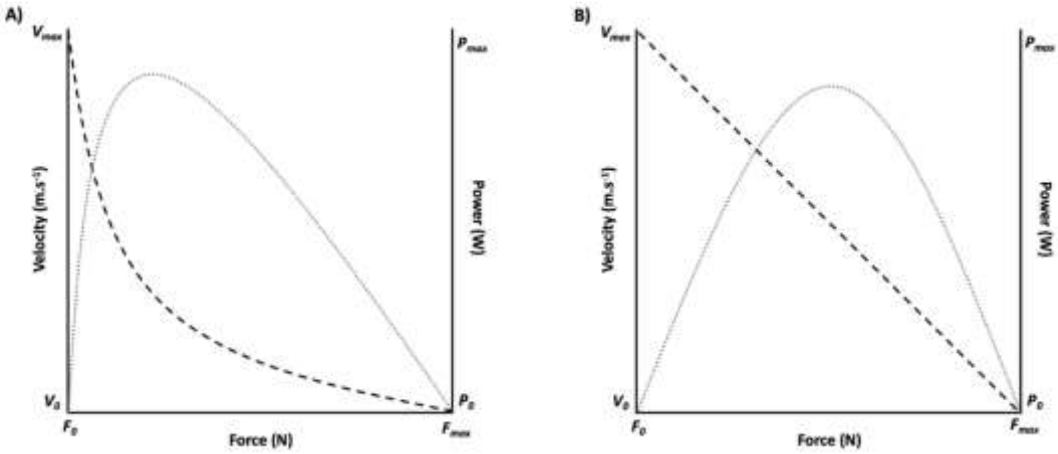


Figure 2. Force-velocity and resultant power-force specific pattern during A) isolated muscular fibres and single-joint dynamic tasks, and B) multi-joint dynamic tasks.

The generation of force is time-constrained in most sporting events (sprinting, jumping, throwing), where the expression of maximal strength is often difficult; it is due to the fact that the time required to apply force in numerous sporting events is shorter than the time needed to express the maximal strength of a given subject (23,79,102). In this case, mechanical variables as the impulse, RFD and muscular power are considered the main determinants of athletic performance (2,3,17,49). For example, Garhammer (51), Schilling et al. (52) and McBride et al. (79) discussed how powerlifters frequently report high values of maximal strength, but when compared with weightlifters, these generated a more rapid force production during dynamic actions, resulting in higher levels of power output. Based on these results, the differences between muscular strength and power indices should be of particular importance for developing athletic performance, and practitioners should be aware of whether it is strength or power in what they need to be focused.

3.3 Training considerations to develop muscular strength and power

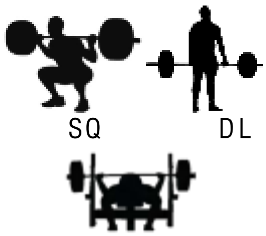
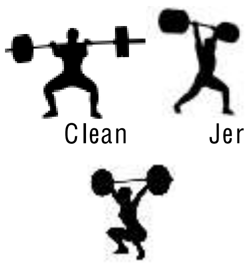
Resistance training is a preferred option to develop both general muscular strength and power adaptations for athletic development (20–23). The training considerations for developing muscular strength and power using resistance training have been well defined in the literature (1–3,22,23,103,113–116). There are three main factors to impact muscular strength and power adaptations: 1) movement pattern specificity, 2) load specificity, and 3) velocity specificity. The combination and application of these factors, along with set configuration, work to rest ratio, and activation strategies lead to several methods (e.g. complex training, cluster training, velocity-based training, post-activation potentiation) frequently used for developing muscular strength and power for athletic performance (2,25,113,117–126).

3.3.1 Traditional strength training exercises with heavy-loads and relatively low movement velocities

Exercise selection may influence the magnitude of performance improvements and the type of adaptations. The squat, deadlift and bench press are compound (multi-joint) exercises that are usually implemented with heavy loads (≥ 70% 1RM) for gaining strength, and subsequently increasing power production (113). Maximal loads can be lifted since these exercises involucre large muscle mass, however, relatively low movement velocities are reported during maximal and submaximal attempts (Table 2)

(127–129). The low movement velocities reported during these exercises are due to the physiological inverse relationship between the force and velocity of the contracting muscle, where heavier loads imply higher forces resulting in lower movement velocities. Furthermore, an inherent deceleration phase is associated with stopping the load at the end of the range of motion during submaximal attempts which results in lower power outputs. (Figure 3) (90,127,128). The deceleration phase referred to "braking phase"; it has been reported to take 28, 18 and 37,1% of the full movement for submaximal efforts during the bench press (20% 1RM), squat (40% 1RM), and deadlift (30% 1RM), respectively (128,130).

Table 2. A description of the velocity registered at 1RM during traditional and weightlifting exercises and their derivatives

Study	Exercise	Velocity at 1RM
Conceiceição et al. (127) Helms et al. (131) Izquierdo (132) Helms et al. (131) Izquierdo (132) Helms et al. (131) Lake et al. (133)	 SQ DL BP	$\geq$ 0.23 $m \cdot s^{-1}$ for the SQ $\geq$ 0.10 $m \cdot s^{-1}$ for the BP $\geq$ 0.14 $m \cdot s^{-1}$ for the DL
Oranchuck et al. (134) Ammar et al. (135) Garhammer et al. (51,136–138)	 Clean Jerk Snatch	$\geq$ 1 $m \cdot s^{-1}$ for the clean, jerk and snatch variations

1RM one repetition maximum, SQ squat, DL deadlift, BP bench press

The deceleration phase is probably the main reason why these exercises are not recommended with lighter loads for power development; although it could be potentially adequate to perform them more rapidly, the deceleration phase extends in order to "break" effectively at the end of the movement resulting in lower forces, lower velocities and subsequently, lower power outputs (Table 2, Figure 3) (127–129). In addition, deceleration phase is related to a significant reduction in the EMG activity of the primary agonist with a coactivation of antagonist muscles involved in the movement (90,139–141). On the contrary, as the load increases, the deceleration phase diminishes as more impulse is needed to complete the lift (127–129). It is important to note that the velocity of the movement is compromised by the natural exercise biomechanics, where a conscience deceleration should not be expected. Instead, a conscious intention to perform the exercise as fast as possible is encouraged and assumed for appropriate adaptations in muscular strength and power for athletic development (52,142–145).

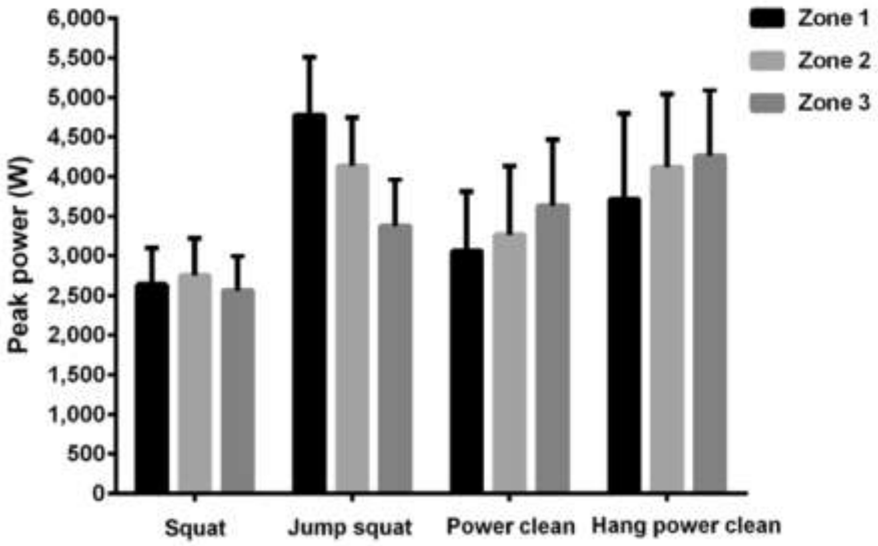


Figure 3. Comparison of power production during traditional (squat), ballistic (jump squat) and weightlifting (power clean and hang power clean) exercises with similar movement pattern but different nature through the power-load continuum. Power outputs were averaged into three zones, where zone 1 ≤ 30% of 1RM, zone 2 ≥ 30% to < 70% of 1RM, and zone 3 ≥ 70% of 1RM. These data have been adapted from a meta-analysis review of 27 studies, modified from Soriano et al. (146) with permission and courtesy of the authors.

3.2.2 Ballistic and plyometric training with relatively light-loads and high movement velocities

Ballistic exercises require athletes to accelerate throughout the entire range of movement to the point of projection (1,2,147). The nature of the ballistic exercises allows for higher movement velocities, forces and power; however, ballistic exercises use relatively lighter loads in comparison to more traditional exercises (Figure 3) (148). For example, Cormie et al (148) reported higher significant ($p \leq 0.05$) peak velocities for the jump squat compared to the squat exercise through the entire power-load continuum (0, 12, 27, 42, 56, 71, 85% 1RM). Furthermore, higher significant ($p \leq 0.05$) peak forces were reported for the jump squat under four loading conditions (0, 12, 71, 85% 1RM), although no significant differences were reported for the rest of loads (27, 42, 56 % 1RM). Similarly, higher significant ($p \leq 0.05$) peak power outputs for the ballistic jump squat were reported for all loading conditions in comparison to the more traditional squat exercise.

The peak and mean velocities, and subsequently, power production of ballistic exercises are higher than non-ballistic traditional exercises because there is no deceleration (i.e. braking) phase (90,149). Similarly, if only the nature of encouraging the full acceleration of the movement is considered, plyometrics are within the classification of ballistic exercises (87,118,150). Plyometric exercises are ballistic indeed but characterized by targeting the SSC of the muscle actions (118,151,152). These include a broad range of unilateral and bilateral jumps, throws, push-ups, and other sport-specific variations (e.g. throws with trunk rotations for rugby players (118,153,154)). Another characteristic is that plyometric exercises are not usually performed with heavy loads; only the athlete' body mass or very light-loads are regularly used in S&C programmes

(154). Therefore, the overloading stimulus is achieved by other strategies such as the number of contacts on the ground, minimizing the duration of the SSC, increasing the height of the drop during drop jumps (which increases the forces of the landing), and promoting the need to push harder (e.g. multiple clap push-ups, jump higher or longer, etc.) (26,154,155). Even, novel approaches either evoke a faster SSC of the muscle actions by reducing the athlete's body mass (126,156) or accentuate the eccentric part of the SSC (157–159).

Ballistic and plyometric exercises are generally more sport-specific, which may facilitate desired adaptations and have consequently, a greater transference to sports performance. Therefore, these exercises are recommended for improving muscular power and pursuing athletic performance (118,147,160–162); however, there are two inherent difficulties in the use of ballistic and plyometric exercises within S&C programmes. First, ballistic and plyometric exercises produce relatively higher peak forces during propulsion and also landing phases that may increase the risk of injury when overused (154,155,163,164). Therefore, these exercises probably suit best to advanced athletes who already possess high levels of muscular strength (3,21,69). A typical prerequisite is to be able to squat double of athletes' body mass 2.0 (1RM/BM) for undertaking specialized high intensity ballistic and plyometric exercises for optimizing power development (3). Second, ballistic (not plyometric) exercises are overloaded across a variety of loading conditions from 0 to 90% of 1RM (148,161,162,165,166). However, when relatively heavy loads are incorporated there is a severe limitation in releasing the weight (e.g. bench press throw) or taking off (e.g. jumping, sprinting) (90,149). Furthermore, the high compression forces of the barbell dropping on the spine during the landing phase of the jump squat and those forces experienced catching the bar during the bench press throw increase the risk of injury severely (90,149). Likely, this is the reason why most researchers and practitioners suggest a restrict use of ballistic exercises with heavy loads (26,31,167).

3.3.3 Weightlifting exercises and derivatives

Researchers have currently suggested that weightlifting exercises and their derivatives may provide a superior stimulus than other resistance-based exercises implemented in training such as ballistic and plyometrics, kettlebells and more traditional exercises (26–30). Higher power outputs are reported in weightlifting exercises and their derivatives in comparison to more traditional exercises as the squat (Figure 3 (51,148,168)).

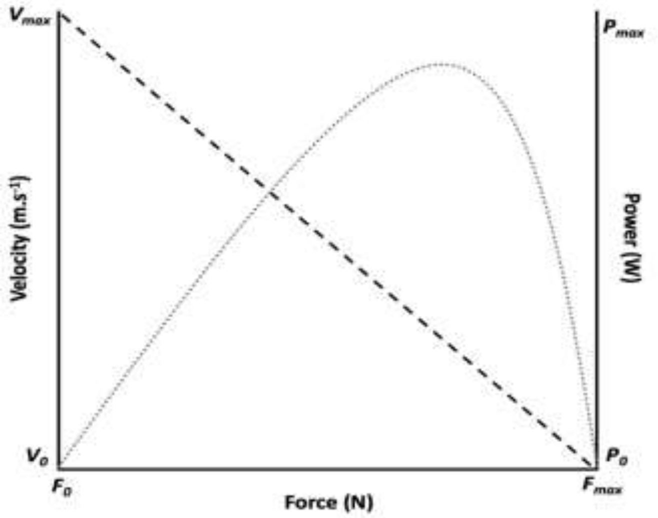


Figure 4. Force-velocity and resultant power-force specific pattern during weightlifting exercises and their derivatives

Weightlifting exercises and their derivatives have a particular nature of displaying high velocities of movement under maximal and near-maximal loads (Table 2 (134,135,138,169,170)) compared to traditional and ballistic exercises. Weightlifting exercises evoke a theoretical shift of the power-force specific pattern with higher power outputs towards the F_{max} end of the force-velocity relationship (Figure 3 and 4 (3,17,51,148,150,171)). Consequently, weightlifting exercises and their derivatives have been recommended to many sports such as football, baseball, volleyball to enhance sports performance by improving muscular strength and power development properties. (24,27,53,78,150,172–177). Additionally, previous research support that weightlifting exercises and their derivatives may train the athlete's ability to "absorb" a load, which, hypothetically, might be beneficial for improving the ability to decelerate (178).

The snatch and C&J are complex whole-body movements performed in weightlifting using a series of high-intensity muscular actions. For the completion of these exercises, weightlifters are required to generate high peak forces, RFD and impulse to adequately accelerate the barbell, consequently resulting in high power outputs (30,50–53). Weightlifting exercises may be further subdivided into weightlifting catching, pulling and overhead pressing derivatives (Figure 5) (24,25,54). Weightlifting catching derivatives require athletes to perform the catch phase; however, in the case of the power clean or power snatch the bar is not caught in a full squat position. The catching derivatives include the following: power clean and power snatch from various positions including the floor, hang at knee, and hang at thigh. Additionally, these lifts can be performed from blocks/plinths at the knee and thigh. In contrast, weightlifting pulling derivatives are those where the catch phase is excluded. Examples of weightlifting pulling derivatives include the snatch and clean pulls from the floor, knee or thigh. These can be performed from a hang or blocks/plinths. The jump shrug, the high pull or the hang high pull are also derivatives that falls into this category (24,25,37,56,179). The WOPD are mainly the PP, PJ and SJ performed from the rack or behind the neck (59).

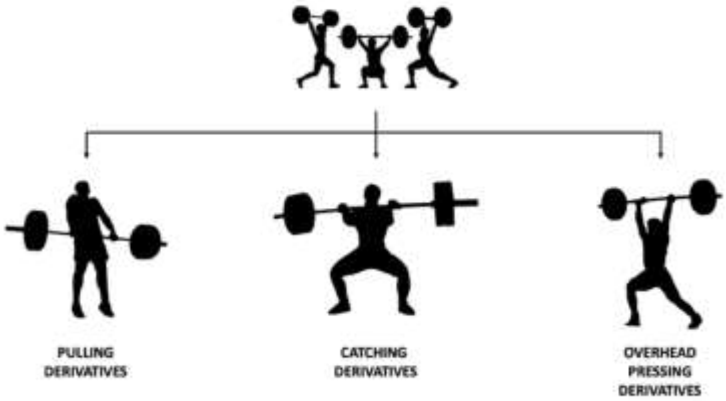


Figure 5. Weightlifting exercises and their pulling, catching and overhead pressing derivatives.

The importance of weightlifting exercises and their derivatives to train lower body muscular power for optimizing the force-velocity profile of athletes (24,25), as well as for enhancing performance in different sporting tasks such as vertical and horizontal jumps (26,31–34), sprinting and change of direction (26,34) has extensively been investigated and reported. During weightlifting exercises and their derivatives, the lower extremities are loaded by the athlete's BM plus the loaded barbell, and mechanical work must be performed to accelerate and raise the centre of mass (CM) of the athlete (101,180–183). That said, researchers have suggested implementing weightlifting exercises and their derivatives to enhance sports performance for several reasons. First, these exercises target under loading conditions the triple extension of the hips, knees and plantar flexion of the ankles, which is an integral part to the successful execution of the majority of the lower-body dynamic actions such as jumping, sprinting and changing of direction (165,184,185). Second, it has been suggested that the coordination and motor control required for weightlifting exercises facilitates the development of a wider spectrum of physical abilities and motor skills (53,78,186).

There are some practitioners who are critics in terms of implementing weightlifting exercises in S&C programmes. The principal reasons include the time that the athletes require for learning in comparison to other exercises (53,78,173), the need of qualified hands-on practice required among practitioners to be able to teach the weightlifting exercises effectively (53,78,150,187), and finally, a common belief that weightlifting exercises are a source of injuries due to the heavy-loads lifted at high-speeds of movement (78,187). However, there is no evidence that weightlifting exercises and their derivatives are more dangerous and cause excessive injuries in comparison to other forms of resistance training or sports (78,87,187). Furthermore, weightlifting derivatives (catching, pulling and overhead pressing) are less time-consuming for learning and require less technical mastery as to complete the full movement is no longer required (24,55,57). Rather, the snatch and the C&J are subdivided into parts to facilitate the process of teaching and learning. In addition, the inclusion of the partial or parallel squat receiving position for the catching derivatives, the exclusion of the catching phase for the pulling derivatives, and taking the bar from racks for the overhead pressing derivatives, are additional strategies that are being utilized to promote a faster learning process, minimize fatigue and technical complexity, and to maximize the benefits of these exercises in pursuing the athletic performance (24,55,57).

3.4 The role of maximal strength in the development of high levels of power and rate of force development

Maximal strength, RFD and power generating capacity are essential attributes that need to be developed when implementing S&C programmes (3,69,70,102). When examining literature, muscular strength is considered the foundational element that underpins physical and performance attributes which influence the ability to generate high RFD and high levels of power (17,69,70,188–190). Stronger athletes not only have reported being able to generate forces more rapidly than their weaker counterparts, but also researchers have reported a decrease in the risk of soft-tissue injuries and better tolerance to higher workloads in team-sport athletes (20,21,81,191–196).

There has been considerable debate concerning how these capacities should be developed to a greater extent when attempting to optimize athletic performance. For example, researchers have suggested that focusing on the development of SPEED-strength resulted in significant increments in sports performance even when relatively light-loads are employed. On the other hand, researchers suggest that targeting the development of STRENGTH-speed with maximal or near-maximal loads usually performed in traditional exercises produces more significant neuromuscular adaptations and changes in athletic performance. However, relatively low movement velocities are assumed during these tasks (70,80,117,126,147,160,167,194,197,198). A theoretical model based on the scientific literature of the load, velocity and power production achieved with the use of the ballistic and plyometrics, weightlifting and derivatives and traditional exercises related to SPEED-strength and STRENGTH-speed demands in S&C programmes has been developed (Figure 6). It may be seen that the use of weightlifting exercises and their derivatives provides a unique stimulus of lifting maximal and near-maximal loads at relatively high movement velocities (Table 2); resulting in higher power development at heavier loads compared to ballistic, plyometrics and traditional exercises (Figure 3 and Figure 6). Nonetheless, researchers and practitioners must be aware that not only exercise selection has a potential influence on the subsequent maximal strength, RFD and power development (2,146), but athlete previous training experience

(2,69,70,73,102,166), the load or range of loads selected (103,146,148,183), and the methodology employed to assess power output have (181,182,184,199–204).

Additionally, the results from a current review support the notion that weightlifting exercises and their derivatives may target not only the STRENGTH-speed part of the force-velocity relationship but the whole force-velocity profile of the athlete resulting in maximizing sports performance (25). Therefore, weightlifting exercises and their derivatives across a range of loads may be effectively employed to target maximal strength, RFD and power development throughout the whole force-velocity profile in athletes.

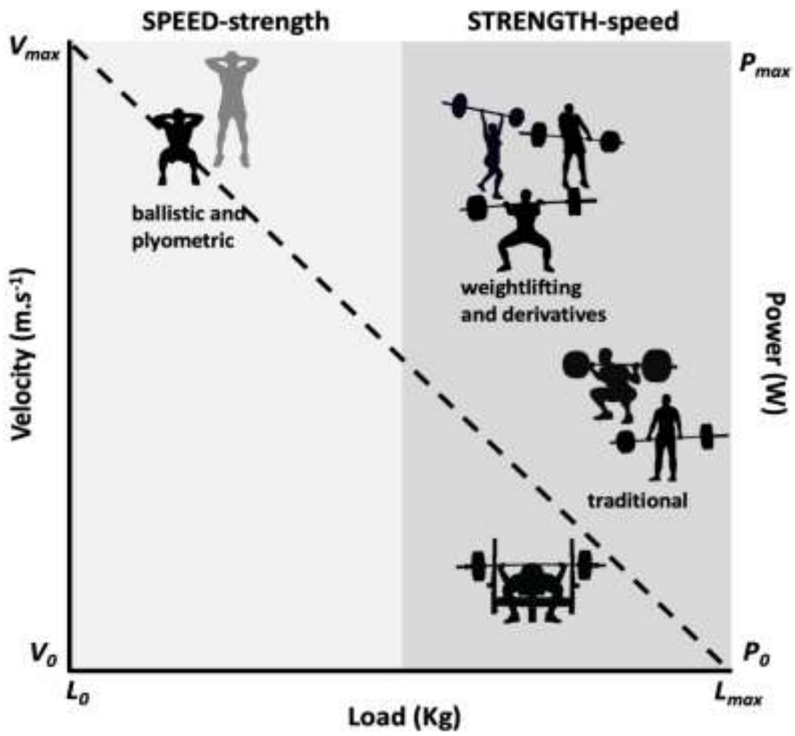


Figure 6. A theoretical model of the load, velocity and power production achieved with the use of ballistic and plyometric, weightlifting and their derivatives and traditional exercises in strength and conditioning programmes.

CHAPTER 4

RESEARCH OBJECTIVES AND HYPOTHESIS

Research objectives and hypothesis

4.1 Study 1

Objectives:

- To provide an insight into the kinetic and kinematic mechanisms underpinning WOPD.
- To provide the rationale for the application of WOPD to resistance training programs to enhance sports performance.

4.2 Study 2

Objectives:

- To determine the validity of performing the three 1RM assessments for the PP, PJ, and SJ in sequence in one testing session (combined assessment method) vs. the criterion method (testing on separate days).
- To determine the between-session reliability of the combined assessment method (1RM assessment for the PP, PJ and SJ).

Hypothesis:

- It was hypothesised that the measures obtained in the combined assessment (PP, PJ, and SJ in sequence in one testing session) would show high agreement and validity respect to the criterion method (1RM single assessment).
- It was also hypothesised that the combined assessment of the PP, PJ, and SJ 1RM would exhibit a high reliability.

4.3 Study 3

Objectives:

- To compare the 1RM performance between three variations of the WOPD (PP, PJ and SJ) for three different sport populations (weightlifters, CrossFit® athletes and a mixed group of athletes).
- To explore the differences in the 1RM performance of these variations across the three sports populations.

Hypothesis:

- It was hypothesised that exercise selection would impact the 1RM performance; and regardless of the sport populations, the 1RM performance would be ranked from the highest to the lowest as follows: SJ, PJ and PP variation.
- It was also hypothesized that weightlifters would present the highest differences in the 1RM for these exercises compared to the other sport populations.

CHAPTER 5

STUDY 1

Weightlifting Overhead Pressing Derivatives: A Review of the Literature

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Abstract

This review examines the literature on weightlifting overhead pressing derivatives (WOPD) and provides information regarding historical, technical, kinetic and kinematic mechanisms as well as potential benefits and guidelines to implement the use of WOPD as training tools for sports populations. Only 13 articles were found in a search of electronic databases, which was employed to gather empirical evidence to provide an insight into the kinetic and kinematic mechanisms underpinning WOPD. Practitioners may implement WOPD such as push press, push jerk or split jerk from the back as well as the front rack position to provide an adequate stimulus to improve not only weightlifting performance but also sports performance as: (1) the use of WOPD is an additional strategy to improve weightlifting performance; (2) WOPD require the ability to develop high forces rapidly by an impulsive triple extension of the hips, knees and ankles, which is mechanically similar to many sporting tasks; (3) WOPD may be beneficial for enhancing power development and maximal strength in the sport population; and, finally, (4) WOPD may provide a variation in training stimulus for the

sports population due to the technical demands, need for balance and coordination. The potential benefits highlighted in the literature provide a justification for the implementation of WOPD in sports training. However, there is a lack of information regarding the longitudinal training effects that may result from implementing WOPD.

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- Realización de la búsqueda bibliográfica / The search of the scientific literature
- Participación principal y mayoritaria en la redacción de todas las secciones del artículo científico / The main contribution to the development of the different sections of the scientific article.

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REVIEW ARTICLE

Weightlifting Overhead Pressing Derivatives: A Review of the Literature

Marcos A. Soriano[1,2] · Timothy J. Suchomel[2,3] · Paul Comfort[2]

Published online: 28 March 2019

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5.1 Study 1 Commentary

This is the first review of the literature on WOPD that discusses not only weightlifting performance but also provides information regarding historical, technical, kinetic and kinematic mechanisms, as well as potential benefits and guidelines for implementing the use of WOPD as a potential method of training for the sporting population. The findings of this study revealed that the use of WOPD such as the PP, PJ or SJ might provide an adequate stimulus to improve sports performance due to the high forces, velocities and power outputs developed. Furthermore, WOPD may provide a variation in training stimulus for the sports population due to the technical demands, need for motor control and coordination, and the ability required to develop force rapidly through a closed kinetic chain.

The potential benefits reviewed in the literature with regard to WOPD may be seen as clear enough reasons to implement them in sports training. However, relatively few investigations have been conducted to date. Only seven studies can be found in the last 20 years. Consequently, the contribution of this review is to establish a starting point, not only to show what has been developed in the literature to date but also stating the need for future research.

CHAPTER 6

STUDY 2

Validity and Reliability of a Standardized Protocol for Assessing the One Repetition Maximum Performance During Overhead Pressing Exercises

Marcos A Soriano[1,2], Amador García-Ramos[3], Antonio Torres-González[4], Joaquín Castillo-Palencia[5], Víctor Ayuso[6], Pedro J. Marín[6] and Paul Comfort[2]

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Abstract

The aim of this study was to determine the validity of performing 3 one repetition maximum (1RM) assessments for the push press (PP), push jerk (PJ), and split jerk (SJ) in sequence in one testing session vs. the criterion method (testing on separate days), while determining the between-session reliability of the combined assessment. Twenty-two well-trained men (n = 22; age: 28.5 + 1.3 years; height: 1.80 + 0.04 m; body mass: 84.9 + 1.9 kg; training experience: 4.3 + 4.1 years) participated in this study. The 1RM was assessed in a sequential order in the same testing session (combined 1RM assessment) for the PP, PJ, and SJ on 2 occasions, to determine between-session reliability. The 1RM for each exercise was also examined on 3 separate sessions to compare the results against the combined method. A high reliability, low variability, and low measurement error were evident for the PP (intraclass correlation coefficient [ICC] = 0.960; coefficient of variation [CV] = 1.8%; smallest detectable difference [SDD] = 7.1%), PJ (ICC = 0.978; CV = 1.5%; SDD = 5.4%) and SJ (ICC = 0.987; CV = 1.2%; SDD = 4.6%). In addition, there were no significant ($p > 0.05$) or meaningful ($\eta^2 \leq 0.001$) differences between the single and combined assessments. The high reliability and validity of the combined assessment suggest that practitioners and researchers may simplify the testing procedure by assessing the 1RM during the 3 main overhead pressing exercises in a single testing session.

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- Revisión de la literatura científica / The review of the scientific literature.
- Selección del protocolo de evaluación y diseño experimental / The selection of the testing protocol and experimental design
- Consecución de la muestra de participantes / The collection of the participants
- Participación principal en la toma y recolección de datos / The main contribution to the assessment and data collection.
- Análisis estadístico / The realization of the statistical analyses

- Participación principal y mayoritaria en la redacción de todas las secciones del documento / The main contribution to the development of the different sections of the scientific article.

Original Research

The Journal of Strength and Conditioning Research

Validity and Reliability of a Standardized Protocol for Assessing the One Repetition Maximum Performance During Overhead Pressing Exercises

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6.1 Study 2 Commentary

The main finding of this study was that the combined assessment of the 1RM performance of the PP, PJ, and SJ, in sequence in one testing session is a valid alternative to the criterion method (single 1RM assessments). Furthermore, both the combined and the single method demonstrated a high agreement, with no systematic bias observed. Also, the combined assessment method is highly reliable with low measurement error for the 1RM performance of the PP, PJ, and SJ in trained lifters. The standard error of measurement (SEM) indicates the range in which an individuals' true score is likely to lie, whereas SDD allows practitioners to decide whether or not a change in an individuals' performance is meaningful. Applying these statistical tools to the results, when assessing changes in the 1RM performance in trained lifters, S&C coaches should look for changes greater than 7.1, 5.4, and 4.6% for the PP, PJ, and SJ, respectively. Any given change placed below these thresholds may be considered as part of the measurement error.

CHAPTER 7

STUDY 3

Comparison of One Repetition Maximum Performance across three Weightlifting Overhead Pressing Exercises and Sport Groups

Marcos A. Soriano[1,2,3], Amador García-Ramos[4], Antonio Torres-González[5], Joaquín Castillo-Palencia[6], Pedro J. Marín[7], Pilar Sainz de Baranda[1] and Paul Comfort[2]

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[7]CYMO Research Institute, Valladolid, Spain.

Abstract

This study aimed to (I) compare the one repetition maximum (1RM) performance between the push press (PP), push jerk (PJ) and split jerk (SJ), and (II) explore these differences between weightlifters, CrossFit® athletes and a mixed group of athletes. Forty-six resistance trained male (age: 28.8 ± 6.4 years; height: 180.0 ± 6.0 cm; body mass: 84.1 ± 10.2 kg; weightlifting training experience: 3.6 ± 3.1 years) participated in this study. The 1RM performance of the PP, PJ and SJ were assessed during the same session in a sequential order (i.e. combined 1RM assessment method). Thirty-six

participants were re-tested to determine between-session reliability of the 1RM values. Intraclass correlation coefficients (ICC) and associated 95% confidence intervals showed a high between-session reliability for the PP (ICC = 0.98 [0.95-0.99]), PJ (ICC = 0.99 [0.98-1.00]) and SJ (ICC = 0.99 [0.98-1.00]). There was a significant main effect of exercise (η^2 = 0.101) and exercise x group interaction (η^2 = 0.012) on the 1RM performance ($p < 0.001$), while the main effect of group did not reach statistical significance ($p = 0.175$). This study provides evidence that the weightlifting overhead pressing derivatives impact the 1RM performance. In addition, the interaction of exercise and sport group was caused by the higher differences in the 1RM performance between-exercises for weightlifters compared to CrossFit® and a mixed group of athletes. Therefore, strength and conditioning professionals should be aware that the differences in 1RM performance between weightlifting overhead pressing derivatives may be affected by the sport group.

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Human Kinetics
ORIGINAL INVESTIGATION

Comparison of 1-Repetition-Maximum Performance Across 3 Weightlifting Overhead Pressing Exercises and Sport Groups

Marcos A. Soriano, Amador García-Ramos, Antonio Torres-González, Joaquín Castillo-Palencia, Pedro J. Marín, Pilar Sainz de Baranda, and Paul Comfort

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7.1 Study 3 Commentary

The present study provides evidence that exercise selection impacts the 1RM performance of the main WOPD (PP, PJ and SJ). Furthermore, practitioners should be aware of that differences in the 1RM performance between WOPD may be affected by the sport populations. Strength and conditioning coaches should be aware of these differences to prescribe the loads adequately and choose the desired exercises for each sports population. The SJ may be more favourable when attempting to increase the maximal strength levels in weightlifters, followed by PJ and PP. However, CrossFit® and the mixed group of athletes may use the SJ and PJ interchangeably when the objective is to increase maximal strength levels. Therefore, this research extends the specificity principle due to the interaction effect of exercise (PP, PJ and SJ) and sports group on the 1RM performance. Additionally, weightlifters presented higher differences in the 1RM performance between-exercises (9-22%), in comparison to the CrossFit® group (4-11%) and the mixed group of athletes (6-14%). This study provides preliminary evidence for future research into a comparison of the variations in the 1RM performances in a long-term structured programme, where the training specificity of each group may have a more significant impact.

CHAPTER 8

DISCUSSION

Discussion

The use of weightlifting exercises and their derivatives may be a powerful stimulus to enhance athletic development (24,25,30,53,78,205). Likely, the potential benefits of these exercises may be due to the fact that heavy-loads are lifted at relatively low movement velocities, resulting in high forces, RFD and power outputs generated by the athlete to accelerate the barbell (36–39,41,42,44,48,51,136–138,206,207). Consequently, S&C coaches should be aware of that weightlifting exercises and their derivatives are beneficial not only for weightlifters but also for the general sporting population.

Sceptical S&C coaches argue that weightlifting exercises such as the snatch and C&J are not as beneficial as they may seem. The main reason is that these exercises require a high level of technical proficiency, motor control and coordination, which results in a considerable investment of time from the S&C coach to teach the proper technique to the athletes (53,78,173). However, the full weightlifting movements snatch and C&J may be subdivided into derivatives or assistant exercises such as the hang power clean, push press, clean or snatch pull which is more applicable for coaches and athletes (24,55,57). The partition of the full movements in different assistant exercises (weightlifting derivatives) promotes a faster learning process and maximizes the benefits of these exercises in pursuing athletic performance for the general sporting population. (24,55,57).

Numerous weightlifting derivatives such as the hang power clean, power clean, hang high pull and mid-thigh clean pull are regularly incorporated into the structured S&C programmes of athletes from different sport disciplines. What is more, the evidence on the improvements in maximal strength and power development based on the kinematic and kinetic analysis (high forces, RFD, power outputs, barbell speeds, etc.) of each variation have been well reported in the literature (35,37–39,41–44,48,208–210). For example, Kelly et al. (43) reported significant greater maximal dynamic strength (expressed as the 1RM) for the power clean performed from the floor (93.33 ± 16.14 kg) in comparison to the power clean performed from the knee (85.63 ± 14.62 kg; $p = 0.04$) and mid-thigh (86.08 ± 17.64 kg; $p = 0.02$) in twelve healthy male subjects. Besides, authors reported strong relationships between all the variations ($r \geq 0.961$, $p < 0.001$). Similarly, Suchomel et al. (39) compared the effect of various loads on the force-time characteristics during the hang high pull and reported statistical differences in peak force ($p = 0.001$), peak velocity ($p < 0.001$) and peak power ($p = 0.015$), with the highest values for each variable occurring at 80, 30 and 45 % of the 1RM of the hang power clean, respectively. These results are of great importance for S&C coaches since exercise selection impacts the kinetic and kinematic stimulus for achieving desired training adaptations.

The potential benefits and rationale to implement weightlifting pulling and catching derivatives based on their particular kinetic and kinematic analysis have been addressed in the literature. However, little information about WOPD had been reported to date. Therefore, the purpose of this doctoral thesis by a compendium of publications was to provide information regarding potential benefits and rationale to implement WOPD in S&C programmes for athletic development.

8.1 Potential benefits and rationale to implement weightlifting overhead pressing derivatives in strength and conditioning programmes

8.1.1 Weightlifting overhead pressing derivatives are mechanically related to sporting tasks

In the study 1, it was demonstrated that the PP, PJ and SJ are complex and powerful multi-joint exercises that generate large forces by the muscles of the lower body, transmitting these through the trunk to the upper extremities (59,63,64,66–68,169). The use of the lower body includes two fundamental movements involved in the half-squat known as the dip (unweighting and braking phase of a quick half-squat) and the thrust or drive (a very rapid propulsion phase via the extension of the hips and knees and plantar flexion of the ankles). These phases are presented in the different variations of the WOPD and are mechanically related to other sporting tasks such as jumping, sprinting or changing of direction, and are considered crucial for developing high power outputs in athletes of different backgrounds (51,206,211).

A strictly vertical movement and optimal time-duration and displacement during the half-squat is required to increase force potentiation and developing high power outputs in the subsequent propulsion phase (the drive) (51,212). It is important to note that the PP differentiates from the jerk variations in the drop under the bar, where the PP requires the athlete to press the bar upward throughout the full extension of the hips, knees and ankles, flexion of the shoulders and extension of the elbows (54,63,65). However, during the jerk variations (PJ and SJ) the subject fully extends the hips, knees and ankles accelerating the barbell upward then subsequently dropping under the bar, to catch the bar, with elbows and shoulders fully extended overhead (54,66–68,212). In addition, there are three different styles for the drop under the bar during the jerk, the split feet position (SJ), the ¼ squat position (PJ) and the full squat position (the squat jerk). Although kinetic and kinematic differences have not been deeply studied to date, the SJ seems to be the preferred style for weightlifters. (54,213,214). However, every athlete has his/her own peculiarities, and a more in-depth study of the differences in the kinematic and technical parameters of the jerk and their variations would be necessary to provide accurate information to S&C coaches to prescribe effective training methods to enhance athletic performance.

Weightlifting exercises and their derivatives have been effective at improving performance in other sporting activities such as sprinting, jumps and changing of direction for several reasons (26,31,34,206). Researchers have suggested that weightlifting training causes different adaptations in the knee muscle co-activation in comparison with traditional resistance training and may result in a superior enhancement of sport performance (215). For example, Cushion et al. (216) reported that the PJ appears to offer an effective strategy to overload joint moment generation in the knee than the jump squat, and therefore, it could offer greater compatibility with tasks that are dominated by knee function or where an athlete needs to develop the knee moment as a 'weak link' (217,218). In contrast, Loturco et al. (219,220) reported that the loaded jump squat exercise was more related to jumping and sprinting abilities than the PP. However, Loturco et al. (219,220) used the PP instead of the PJ or SJ, where the jerk variations are known to be faster exercises with unique proximal to distal recruitment strategy that is more related to improving jumping and sprinting performance (185,217,221). Nonetheless, such a controversy shows the need to study WOPD and their relationships to sporting tasks in greater depth, and consequently, also athletic performance.

8.1.2 Weightlifting overhead pressing derivatives contribute to increasing maximal strength and power development

Current evidence suggests that weightlifting training enhances athletic performance that requires heavy-load speed-strength (150). Accordingly, WOPD are exercises where large loads are lifted to an overhead position, and to succeed in the lift; it has to be performed at relatively high movement velocities (51,138,212,222). The combination of the two variables, the force, due to the heavy loads that can be lifted, and velocity, due to the high barbell velocities, results in a unique stimulus to achieve high levels of power outputs that may target the ability to develop rapid force production (RFD) and also power development necessary to enhance athletic performance (51,53,150).

In study 1, an extensive review of the literature was undertaken to provide empirical evidence to give an insight into the kinetic and kinematic mechanisms underpinning WOPD. Studies that have investigated the kinetics and kinematics during these exercises have reported large power outputs, forces, and relatively high barbell speeds, comparable to other dynamic tasks. For example, Lake et al. (82) found that the peak power output during the PP was not significantly different compared to the jump squat (3640.1 ± 573.8 vs 3885.2 ± 302.3 W, respectively). Furthermore, the loads at which the peak power was maximized tended to be heavier in the PP in comparison to the jump squat (81.3 ± 9.9 vs 52.5 ± 25.5% 1RM). Similarly, Garhammer (136–138) reported very high values from 2500 to 6953 W for peak power output during the jerk, which were comparable with those reported for the second pull of the snatch and the clean. A current limitation is that the majority of studies that have analysed the WOPD included highly experienced weightlifters (136–138,212). Consequently, it is difficult to extrapolate these data to the general sporting population, since highly experienced weightlifters are technically proficient and perform differently to their less-skilled counterparts (212,223–225).

In study 3, the aim was to compare the 1RM performance between three variations of the WOPD (PP, PJ and SJ) for three different sport populations (weightlifters, CrossFit® and a mixed group of athletes) to obtain a more in-depth knowledge of the impact of exercise and sports group. The results of this study revealed a significant main effect of exercise ($p < 0.001$; $\eta^2 = 0.101$) and exercise x group interaction ($p < 0.001$; $\eta^2 = 0.012$) on the 1RM performance, while the main effect of group did not reach statistical significance ($p = 0.175$; $\eta^2 = 0.066$). Study 3 provides evidence that exercise selection impacts the 1RM performance between the PP, PJ and SJ, which may be because of subtleties in the technique that result in those differences as it has been previously reported for the power clean variations (43).

The findings of study 3 extend the specificity principle due to the interaction effect of exercise (PP, PJ and SJ) and sports group on the 1RM performance. Weightlifters presented higher differences in the 1RM performance between-exercises (9-22%), in comparison to the CrossFit® group (4-11%) and the mixed group of athletes (6-14%). The weightlifters' SJ was the most discriminative exercise as this presented the most significant difference in performance between the three groups ($p < 0.001$); however, no significant differences were found between the PJ and SJ for the CrossFit® ($p = 0.9$) and the mixed group of athletes ($p = 0.11$). Although these differences may be attributable to a wide range of physiological and psychological factors (49,113,207) these results support the specificity training principle (79,226), where the weightlifters report superior technical mastery during the SJ as it is part of official weightlifting competitions, resulting in a discriminative role for being highly trained in this group (207,227).

It is important to note that from a biomechanical standpoint, the SJ should be the exercise where the largest loads are lifted for all individuals given that less displacement of the barbell is required due to the drop under the bar in the split feet position (51,68,207,212). However, the inclusion of athletes from different sport disciplines (CrossFit®, rugby union, track and field and volleyball) could explain the lack of differences observed in study 3 between the PJ and SJ for the non-skilled weightlifters (CrossFit® and the mixed group of athletes). The practical application of this study is essential for S&C coaches that should be aware of these differences to prescribe the loads and exercises adequately to achieve the desired adaptations for athletic development. Furthermore, this study provides preliminary evidence for future research into a comparison of the variations in the 1RM performances in a long-term structured programme, where the training specificity of each group may have a more significant impact.

8.1.3 Weightlifting overhead pressing derivatives challenge the development of motor control and coordination

Implementing WOPD as the PP, PJ or SJ in S&C may be a useful tool for athletic development (63–65,78,217). WOPD require the ability to develop force through the kinetic chain from the lower to the upper extremities, which may be a powerful stimulus to strengthen muscles of the upper body and lower body while optimizing motor control and coordination, due to the key role of the trunk and lower body muscles in stabilizing and transmitting forces in a closed kinetic chain (59,228–230). Additionally, the PP, PJ or SJ are highly applicable to time-constrained events and sports than more traditional exercises such as the squat or the bench press, due to the technical challenges requiring speed, acceleration, timing and coordination. (63–65,82,217).

8.2 Implementing weightlifting overhead pressing derivatives in structured strength and conditioning programmes

The potential benefits of implementing WOPD to enhance athletic performance in general sports population have been well discussed in previous paragraphs. However, since this population are not skilled and competitive weightlifters, they may not assume the same programming characteristics used by highly experienced weightlifters (78,173,227). Consequently, adequate coaching and training strategies to implement the WOPD in a sports training programme remains to be determined.

The actual programming of WOPD adapted to a sports program depends on the sport, the desired objective, and the time of the year that is taking place (53,78,214). The main benefits of weightlifting exercises within a structured S&C programme are best attained by strategically using the many weightlifting variations according to their technical-complexity properties, and SPEED-strength to STRENGTH-speed demands (24,25,53,54,59,78,173,214). Suchomel et al. (25) developed a theoretical model where the entire force-velocity profile of the athletes may be enhanced using weightlifting exercises and their derivatives (Figure 7).

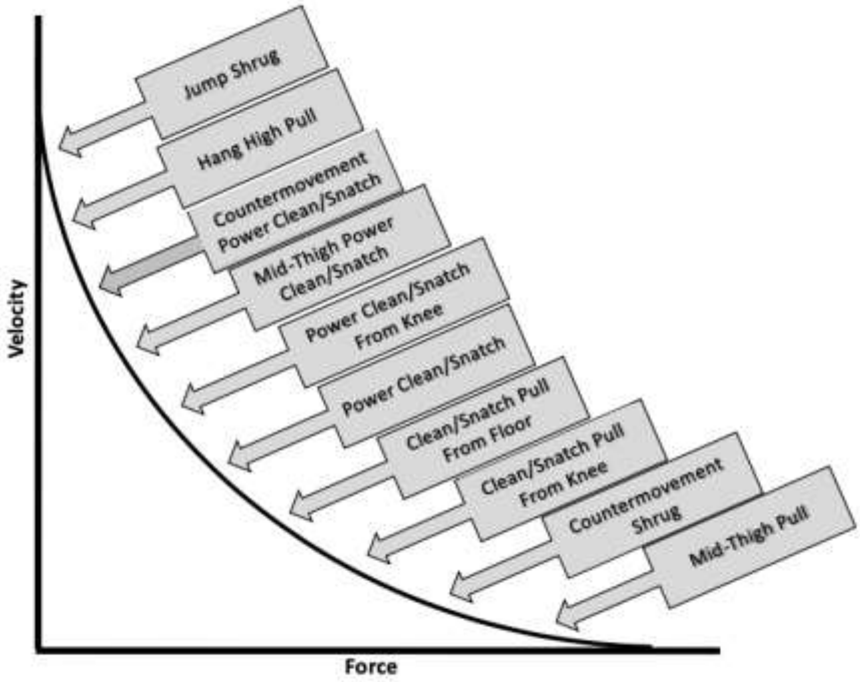

Figure 7. A theoretical model to target the entire force-velocity profile of a given athlete using weightlifting exercises and their derivatives. Modified from Suchomel et al. (25) with permission and courtesy of the authors.

The model reflects that each variation may provide a different stimulus for targeting SPEED-strength to STRENGTH-speed capabilities. For example, athletes have achieved higher barbell velocities during the jump shrug or the hang high pull, and therefore, these exercises may be a valid strategy to enhance the physiological ability of the muscles to shorten at high-speeds (24,36,37,56,179). On the contrary, the mid-thigh pull has been overloaded with a load equivalent to 140% of the 1RM (41,48). Moreover, athletes have reported high peak forces during the mid-thigh pull and clean pulls across studies, which determines the ability of these exercises to target the force generation capacity of the neuromuscular system (24,42,48,189). It is important to note that any given exercise of the model may be positioned in one or the other end of the force-velocity relationship depending on the magnitude of the load at which is overloaded (25); however, the model has been developed based on data previously reported on the kinetic and kinematic analysis of weightlifting exercises and their derivatives (35–42,44,48,76,179,208,209).

Empirical evidence indicates that implementing weightlifting exercises and their derivatives may be a useful strategy to enhance sports performance, but the success may be negated if an incorrect technique is applied (24,25,53,54,59,78,173,214). Moreover, an adequate progression must be adopted to facilitate and reduce the time-consuming learning process, to reduce the risk of injury associated with a poor technique, and to assure the benefits of implementing WOPD into a structured S&C programme (45,46,78,173,214,231). Previous research on exercise technique and strength and power development of the WOPD suggest that a correct technical execution and progression is just as critical for success as choosing the right exercise (54,59,63,64,66–68,82,211,214,223,224,232).

A theoretical approach similar to the model developed by Suchomel et al. (25) has been created to cover the adequate progression attending to (i) technical complexity and (ii) SPEED-strength to STRENGTH-speed demands of the main WOPD (PP, PJ and SJ) (Figure 8). Although kinetic and kinematic analysis has not been performed within this doctoral thesis, the present model has been developed following the results obtained from study 1 and study 3. Garhammer (233) suggested that the ability to lift heavier loads depends greatly upon the ability of the lifter to achieve higher power production. Then the results of study 3 suggest that the SJ should achieve the highest power outputs followed by the PJ and the PP, although it has not been compared in the scientific literature to date.

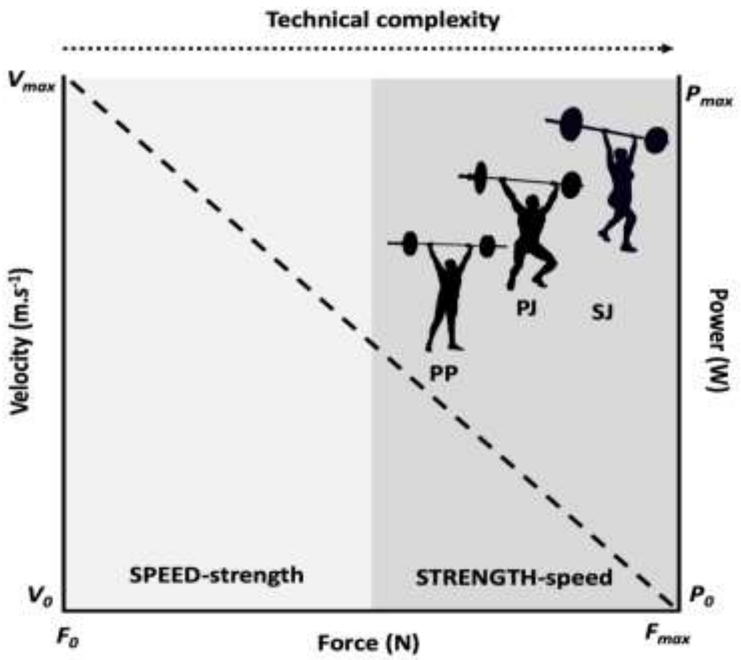

Figure 8. A theoretical model to illustrate the strength and power demands of the main weightlifting overhead pressing derivatives through the force-velocity relationship and technical complexity. PP (push press), PJ (push jerk), SJ (split jerk).

In summary, it may be useful to strategically use the performance parameters and progression according to technical complexity. Firstly, the usual process starts from the development of the least complex exercise, the PP, to form the basis of upper body strength, shoulder and thoracic complex mobility and the overall motor control during the propulsion phase of the lower body (59,63,64,214,228,229). Then, the progression to more whole and challenging body STRENGTH-speed demanding exercises such as the PJ and SJ will be followed (59,63,66,67,214). An adequate technical complexity progression should follow that order. Interestingly, in the WOPD as the technical complexity increases, the load that may also be lifted increases, as demonstrated by the higher 1RM performance of the SJ and PJ of the athletes of different backgrounds in comparison to the less technical exercise PP in study 3.

Finally, more experienced lifters may implement more complex variations as the squat jerk to target specific muscles and challenge the overall motor control and coordination to a higher level (53,213). Athletes may choose to potentiate as a preferred exercise any of the jerk-styles (PJ, SJ and squat jerk) and the election will depend on individual characteristics of the lifters and the learning process that has been applied (54,66,67,214). However, based on the evidence that heavier loads may be lifted in the SJ (study 3), S&C coaches should develop a progression where athletes of different sports learn to master the SJ style for strength and power development, resulting in an enhancement of athletic performance.

8.3 Assessing the one repetition maximum performance of weightlifting overhead pressing derivatives

Muscle strength is a key determinant of dynamic athletic performance, and as such, accurate assessment of an individual's muscular strength is crucial as a part of a comprehensive athlete-monitoring plan (69,70,74). The 1RM is the preferred test used by S&C coaches for the assessment of maximal dynamic strength because it is comparatively simple and requires relatively inexpensive equipment (74,75). Furthermore, because the 1RM test can be performed using the same exercises as those undertaken during regular training, it is considered as the gold standard for assessing maximal strength and can be used to prescribe training loads for subsequent phases of training (74,75).

The PP, PJ and SJ are weightlifting pressing variations that are commonly included in the training programmes of sporting populations (59). Few studies had reported the 1RM performance of these exercises (82,234,235). However, only Comfort et al. (235) had reported between-session reliability (ICC = 0.910) for the 1RM during PP. No researchers seemed to have reported the reliability and measurement error of the

1RM PP, PJ or SJ. Therefore, since the PP, PJ, and SJ are used throughout S&C programmes, it seemed necessary to assess the between-session reliability of the 1RM performance. Furthermore, as it is not time efficient to assess each 1RM performance on separate days, with no published equation to predict the 1RM performance in one task from another; a novel method was designed in study 2 for the assessment of the 1RM performance of the three exercises, in sequence, in one testing session.

The results of study 2 demonstrated that a combined assessment method used to assess the 1RM performance during three weightlifting overhead pressing variations (PP, PJ and SJ), in sequence, in one testing session is highly reliable and valid and a more time-efficient method in comparison to the single assessment (testing each exercise in separate sessions). A summary of the 1RM combined assessment protocol sequence is presented in figure 9. In brief, the 1RM in PP served as a preparation exercise for the PJ and both for the SJ because all these exercises have similar movement pattern and nature (59). The hypothesis of this novel method was based on empirical evidence from weightlifting coaches experience. They reported that the PP, PJ, and SJ followed a sequence order in terms of the 1RM performance with marked differences in the 1RM performance between exercises; however, there was no published study supporting this thought.

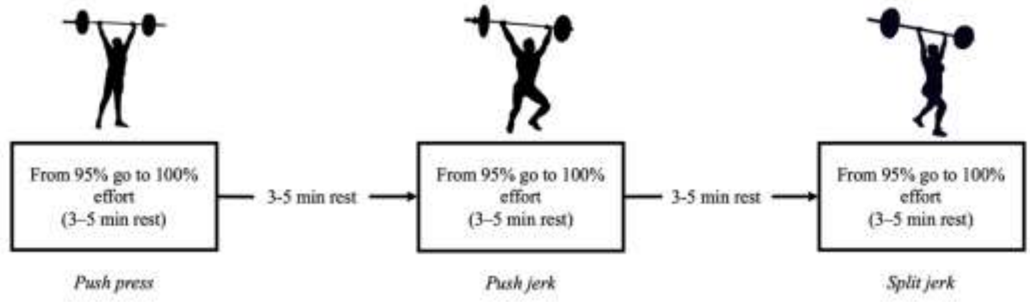

Figure 9. Protocol sequence of the combined one repetition maximum assessment method.

Study 2 demonstrated several applications of practical importance to researchers and practitioners including; first, the validity of the combined assessment method to assess the 1RM during the three main WOPD (PP, PJ and SJ) being more time-efficient with no presence of fatigue, at least, not affecting the 1RM performance. Second, the high reliability, low variability and low measurement error were evident for the three exercises (PP, PJ and SJ), which may suggest that there was no presence of fatigue or learning effects between-sessions. Third, researchers and practitioners should look for changes greater than 7.1, 5.4, and 4.6% for the PP, PJ, and SJ, respectively. Any given change placed below these thresholds may be considered as part of the measurement error. Nonetheless, several limitations should be noted in study 2. (I) The sample size and training status may be a limiting factor in the generalizability of these findings (75). Note that the high consistency in 1RM performance observed in this study could be explained by the high weightlifting expertise of the subjects. (II) The 1RM performance in exercises that require a complex technique as weightlifting derivatives may be affected by other factors rather than neuromuscular fatigue or learning effects, including self-efficacy, lack of concentration, and attentiveness (236). Therefore, research on less-experienced population should provide a better understanding of the 1RM assessment during WOPD.

CHAPTER 9
CONCLUSIONS

Conclusions

This thesis is the first work focused on the potential benefits and rationale for the implementation of WOPD in S&C programmes for athletic development. Various conclusions and practical applications may be highlighted from this work:

- The use of the main WOPD (PP, PJ, and SJ) may provide an adequate stimulus to improve not only weightlifting performance but also sports performance for several reasons:
  a) The use of WOPD is a useful and well-supported strategy to improve weightlifting performance, due to the high number of failed attempts during the jerk phase in weightlifting competitions (237–239).
  b) WOPD require the ability to develop force rapidly through the closed kinetic chain of the lower extremities, which is mechanically similar to many sporting activities (63,206,216). This movement pattern targets not only an impulsive triple extension of the hips, knees and plantar flexion of the ankles, but also optimizes motor control and coordination due to the key role of the trunk and lower body muscles in stabilizing and transmitting forces in the closed kinetic chain (228–230).
  c) WOPD may be beneficial for enhancing power development and maximal strength in the sports population. This is supported by literature that has reported that WOPD develop high forces and RFD, resulting in high levels of power development since heavy-loads can be lifted at high movement velocities (51,53,150,222).

- The high reliability and validity of the combined assessment suggest that practitioners and researchers may simplify the testing procedure by assessing the 1RM during the three main WOPD (PP, PJ, and SJ) in a single testing session based on the following findings:
    a) There were no significant or meaningful differences in the 1RM performance when performing the 1RM during the PP, PJ and SJ in sequence, in one testing session (combined assessment method), in comparison to performing a single assessment method (PP, PJ or SJ separately).
    b) The combined assessment method demonstrates high reliability, low variability, and low measurement error for the PP, PJ and SJ weightlifting pressing variations.

- The exercise selection of the main WOPD impacts the 1RM performance. The SJ is presumably the exercise where the largest loads are lifted, followed by the PJ and PP. Therefore, practitioners should be aware of these differences to implement the SJ followed by the PJ and finally, the PP when the development of maximal strength is the objective of training for athletic development.

- Higher differences have been reported in the 1RM performance between-exercises for skilled weightlifters compared to CrossFit® and a mixed group of athletes. These findings support the specificity training principle due to the differences caused by the interaction of exercise and sport groups. Practitioners should be aware of these differences to prescribe the loads and exercises adequately to achieve the desired adaptations for athletic development.

9.1 Study limitations and future research

After the completion of this work, several potential limitations and research questions need to be addressed. First, the primary limitation is the limited research conducted to date and the reduced progression registered in the last 20 years, with only seven articles focused on the main WOPD. For example, before this work, it was not published evidence of the differences in the 1RM performance between the main WOPD exercises (PP, PJ and SJ) or the reliability values for each exercise during the 1RM assessment. Second, there is a lack of understanding regarding the kinetic and kinematic data on the main WOPD across loads. Third, the majority of studies that have analysed the WOPD were conducted by highly trained weightlifters (51,136–138,212,234). However, in line with our results for the 1RM performance between exercises, skilled and experienced weightlifters lift differently compared to non-skilled lifters (212,223,225,240). The differences in training status are certainly one of the reasons why is challenging to compare between studies, and therefore, to extrapolate the results of kinetic and kinematic data reviewed in the literature to other sporting populations. Therefore, further research on the kinetic and kinematic mechanisms of the main WOPD (PP, PJ and SJ), across loads, in sporting populations, is guaranteed to include a better understanding of the topic.

The differences in the 1RM performance between the main weightlifting pressing variations and the interaction effect with sport group have been addressed in this work. However, there is little information regarding the implementation of WOPD in a structured S&C programme, and the subsequent adaptations in 1RM performance. Furthermore, the inclusion of more and less skilled lifters could result in differences in

1RM performance. These limitations, taken as a whole, certainly pose a research question that needs to be addressed.

CHAPTER 10

CONCLUSIONES

Conclusiones

Esta tesis ha sido el primer trabajo que se ha centrado en los beneficios potenciales y la fundamentación de implementar los WOPD en programas de fuerza y acondicionamiento físico para el desarrollo deportivo. Diversas conclusiones y aplicaciones prácticas se extraen de este trabajo:

- El uso de los principales WOPD (PP, PJ y SJ) puede proporcionar un estímulo adecuado para mejorar no solo el rendimiento sobre el deporte de la halterofilia, también el rendimiento deportivo en deportistas no halterófilos por diferentes razones:
  a) La aplicación de los WOPD es una estrategia bien documentada y útil para la mejora del rendimiento en el deporte de la halterofilia, debido al alto número de intentos fallados en la fase del envión en competiciones de halterofilia (237–239).
  b) Los WOPD requieren de la capacidad para desarrollar fuerza rápidamente a través del movimiento en cadena cinética cerrada de las extremidades inferiores, que es mecánicamente similar a muchas acciones deportivas (63,206,216). Este patrón de movimiento desarrolla una potente triple extensión de la articulación de la cadera, rodilla y flexión plantar de los tobillos, así como optimiza el control motor y la coordinación dado el rol clave de las extremidades inferiores y el tronco en la estabilización y la transmisión de fuerzas en dicha cadena cinética cerrada (228–230).
  a) Los WOPD pueden ser beneficiosos para mejorar el desarrollo de potencia y fuerza máxima en deportistas de diferentes disciplinas. Esto está documentado por la literatura científica donde se proporciona la evidencia de que los WOPD

desarrollan picos altos de fuerza, valores altos de RFD, que resultan en niveles altos en el desarrollo de potencia, dado que estos ejercicios tienen la propiedad de que cargas pesadas pueden ser levantadas a altas velocidades de movimiento (51,53,150,222).

- La alta fiabilidad y validez del método de evaluación combinado sugiere que entrenadores e investigadores pueden simplificar el procedimiento de los test evaluando la 1RM en los principales WOPD (PP, PJ y SJ) en una única sesión, atendiendo a los siguientes hallazgos:
  a) No se encontraron diferencias significativas en el rendimiento de la 1RM, habiendo realizado el PP, PJ y SJ en orden secuencial, en una única sesión de test (método de evaluación combinado), en comparación con la evaluación de cada ejercicio de manera particular.
  b) El método de evaluación combinado demuestra una alta fiabilidad, baja variabilidad y un bajo error de medición para el PP, PJ y SJ.

- La selección del ejercicio en los principales WOPD influye en el rendimiento de la 1RM. El SJ es presumiblemente el ejercicio donde se levantan las cargas más pesadas, seguido por el PJ y el PP. Por tanto, los profesionales del ejercicio físico deben de ser conscientes de estas diferencias e implementar el SJ seguido del PJ y finalmente, el PP cuando el objetivo del entrenamiento sea desarrollar la fuerza máxima para favorecer el desarrollo deportivo.

- Existen mayores diferencias en el rendimiento de la 1RM entre ejercicios por parte del grupo de halterófilos experimentados en comparación con los practicantes de

CrossFit® y el grupo mixto de deportistas. Estos hallazgos apoyan el principio de especificidad en el entrenamiento dadas las diferencias causadas por la interacción del ejercicio y el grupo deportivo. Los profesionales del ejercicio físico deben ser conscientes de estas diferencias para prescribir las cargas y los ejercicios adecuadamente, en función de las adaptaciones que se pretendan conseguir para favorecer el desarrollo deportivo.

10.1 Limitaciones de estudio y futuras áreas de investigación

Existen importantes limitaciones y preguntas experimentales que necesitan de más investigación. Primera, una limitación crítica es que se trata de un área de investigación muy limitada con una progresión muy reducida en los últimos 20 años, con sólo 7 artículos publicados para los WOPD. Por ejemplo, antes de la realización de este trabajo, no se encontraban indicios en la literatura científica entre las diferencias del rendimiento de la 1RM entre los principales WOPD (PP, PJ y SJ) o los valores de fiabilidad de cada ejercicio en la evaluación de la 1RM. Segunda, existe una falta de conocimiento sobre las diferencias cinéticas y cinemáticas entre los principales WOPD con el uso de diferentes cargas (intensidades). Tercera, la gran mayoría de estudios que han analizado los WOPD han sido desarrollados en una población de halterófilos experimentados (51,136–138,212,234). Sin embargo, y en concordancia con nuestros resultados sobre el rendimiento de la 1RM entre ejercicios, los halterófilos experimentados presentan diferencias en los levantamientos en comparación con deportistas experimentados no halterófilos (212,223,225,240). Las diferencias en el nivel de entrenamiento son ciertamente una de las razones por las cuales resulta difícil comparar entre estudios, y por lo tanto, extrapolar los resultados de variables cinéticas y cinemáticas revisadas en la literatura científica con deportistas no halterófilos. Consecuentemente, es necesaria más investigación sobre los mecanismos cinéticos y cinemáticos de los principales WOPD (PP, PJ y SJ), con diferentes cargas (intensidades), aplicados en deportistas no halterófilos, con el fin de obtener un mayor entendimiento sobre esta área de conocimiento.

Las diferencias en el rendimiento de la 1RM entre los principales WOPD y la interacción atendiendo al grupo deportivo se han investigado en este presente trabajo. Sin embargo, es necesaria más información sobre la inclusión de los WOPD en programas de fuerza y acondicionamiento físico estructurados, así como de las subsecuentes adaptaciones en el rendimiento de la 1RM. Además, la inclusión en futuros estudios de sujetos más y menos experimentados podría resultar en diferencias en el rendimiento de la 1RM. Estas limitaciones, en conjunto, muestran una clara necesidad de investigación en esta área de conocimiento.

CHAPTER 11

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APPENDIX I

Research, Enterprise and Engagement
Ethical Approval Panel

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4 March 2019

Dear Marcos,

RE: ETHICS APPLICATION–HSR1819-060 – 'Weightlifting overhead pressing derivatives. Analysis of kinetic and kinematic variables and methodology of assessment.'

Based on the information that you have provided, I am pleased to inform you that ethics application HSR1819-060 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Professor Sue McAndrew
Chair of the Research Ethics Panel

APPENDIX II

APPENDIX 1

PARTICIPANT INFORMATION SHEET (Version 1, 15/01/2019)

Title of study: Differences in kinetics and kinematics during weightlifting overhead pressing derivatives across a range of exercise variations and loads.

Name of Researcher: [redacted]

Invitation paragraph

I am inviting you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully and please feel free to ask questions if anything you read is not clear or would like more information before deciding on taking part.

What is the purpose of the study?

The purpose of this study is to identify the main differences on kinetics and kinematics across a range of weightlifting overhead pressing exercises, and how the impact of different loads may affect these variables.

Why have I been invited to take part?

You have been invited to take part within this study because you have expressed an interest in the testing that is taking place. You are also deemed to be of an adequate physical fitness and possessing experience in Olympic lifting where you participate in physical activity regularly.

Do I have to take part?

It is up to you whether you wish to take part. You will be asked to read this sheet and sign a consent form at least 24 hours prior to testing. Also, if you change your mind after signing the consent form you have no obligations to take part and can withdraw at any point. You do not need to provide a reason for withdrawing and this will not affect the standard of care and input you receive.

What will happen to me if I take part?

You will be asked to attend 2 to 4 testing sessions separated by a seven-day period at least, with each session taking a maximum of 1,5 hours.

On the first testing occasion, one repetition maximum will be tested across a range of weightlifting overhead pressing derivatives. The session will be supervised by qualified sport coaches and researchers who will assess not only that the protocol is being developed adequately but also the technique is being developed safety so the participants do not have any risk of injuries.

Figure 1: Picture of the jerk exercise, corresponding to one of the exercise which will be assessed.

The session will involve a standardised warm-up following previous guidelines, and after a pause, subjects will be involved in one repetition maximum protocol during weightlifting overhead pressing derivatives using a modified version previously set. Subjects will try to reach the one repetition maximum in each exercise.

On the second testing occasion, the protocol followed on the first session will be exactly replicated. The main goal of this will be to stablish an adequate intra-class correlation coefficient to validate the measures.

On the third testing occasion, some of the subjects involved on the first and second testing session will attend our studies to assess the main differences between kinetics and kinematics during variations of the weightlifting overhead pressing derivatives. The session will involve a standardised warm-up and after a pause, a load which corresponds to a percentage of the one repetition maximum previously tested will be selected, and the main differences between kinetics and kinematics will be tested and analysed for the different exercise variations by the research.

On the fourth testing occasion, some of the subjects involved on the first and second testing session will attend our studies to assess the main differences between kinetics and kinematics during variations of the weightlifting overhead pressing derivatives across a range of loads. The test will follow the same guidelines reported previously.

Expenses and payments?

NONE

What are the possible disadvantages and risks of taking part?

A disadvantage or risk of taking part will be performing maximal physical test, resulting in an increased injury risk. However, you will complete a health questionnaire prior to all testing and you will be supervised in every moment for qualified coaches and researchers to make sure the you are of an adequate level of physical fitness that will mitigate these risks.

What are the possible benefits of taking part?

One benefit of taking part is that you are learning in the research which is related to weightlifting overhead pressing derivatives, learning in identification of how to appropriately train to improve your lifts and your sport performance. A further benefit of taking part is that the researcher will then be able to provide you appropriate technique assessment and coaching of the resistance exercises, to optimise your own technique. As well as additional research supported information to learn your training with regards to volume, intensity and status of training respect to the different populations involved.

What if there is a problem?

'If you have a concern about any aspect of this study, you should ask to speak to the researcher ([redacted]) who will do their best to answer your questions. If you remain unhappy and wish to complain formally you can do this by contacting the Research Supervisor ([redacted]). If the matter is still not resolved, please forward your concerns to Professor Susan McAndrew, Chair of the Health Research Ethical Approval Panel, Room MS1.91, Mary Seacole Building, Frederick Road Campus, University of Salford, Salford, M6 6PU. Tel: 0161 295 2778. E:s.mcandrew@salford.ac.uk'

Will my taking part in the study be kept confidential?

Yes, we take great care to protect the confidentiality of the information we are given, and we take careful steps to ensure that data are secure at all times. The information collected is used for research purposes only and is dealt with according to the 2018 data protection act and the 2018 general data protection regulation (GDPR) guidelines. The information that you provide will be stored anonymously on a computer/hard drive and any hard copies of documents will be stored in a locked filing cabinet by the research supervisor. None of the information held by the researcher will identify you by name. Information from this study may be made available to other researchers at the University of Salford and elsewhere for future research studies; however, no information in this anonymised dataset can been used to identify individuals.

What will happen if I withdraw from the study?

If you decide to withdraw from the study all information and data collected from you, to date, will be destroyed and your name removed from all the study files. With a withdrawal period of 1 month after the final session has been completed.

What will happen to the results of the research study?

Any data gathered during this research will initially be used for my PhD thesis. I will also attempt to publish data from this study which will be made available to you. All information gathered will be published keeping all subjects anonymous.

Who is organizing or sponsoring the research?

The research is organized through the University of Salford with no sponsorship.

Further information and contact details:

If you have any further questions about this research, please do not hesitate to contact me directly.

Researcher:
[redacted]

Health Research Ethics Application Form

APPENDIX 2

CONSENT FORM (Version 1, 15/01/2019)

Title of study: Differences in kinetics and kinematics during weightlifting overhead pressing derivatives across a range of exercise variations and loads.

Name of Researcher: [redacted]

Please complete and sign this form **after** you have read and understood the study information sheet. Read the following statements, and select 'Yes' or 'No' in the box on the right hand side.

1.	I confirm that I have read and understand the study information sheet ***Version 1***, dated ***15/01/2019***, for the above study. I have had the opportunity to consider the information and to ask questions Which have been answered satisfactorily.	Yes/No
2.	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, and without my rights being affected.	Yes/No
3.	If I do decide to withdraw, I understand that the information I have given will be destroyed. The timeframe for withdrawal is up to 1 month after the final testing session.	Yes/No
4.	I agree to participate by attending and completing the testing occasions, described in the information sheet.	Yes/No
5.	I understand that my personal details will be kept confidential for a period of three years and will not be revealed to people outside the research team.	Yes/No
6.	I understand that my anonymised data will be used in the researchers' thesis, and it will be kept in the university repository for the use of academic purposes and other researche related topics.	Yes/No
7.	I agree to take part in the study: Differences in kinetics and kinematics during weightlifting overhead pressing derivatives across a range of exercise variations and loads.	Yes/No

Name of participant	**Date**	**Signature**

Name of person taking consent **Date** **Signature**

APPENDIX 3

Risk Assessment Form (Version 1, 15/01/2019)

ALL projects MUST include a risk assessment. If this summary assessment of the risk proves insignificant, i.e. you answer 'no' to all of the questions, then no further action is necessary. However, if you identify any risks then you must identify the precautions you will put in place to control these.

1. What is the title of the project?

Differences in kinetics and kinematics during weightlifting overhead pressing derivatives across a range of exercise variations and loads.

2. Is the project purely literature based? **NO**

If YES, please go to the bottom of the assessment and sign where indicated. If NO, then please complete section 3 and list your proposed controls.

3. Please highlight the risk(s) which applies to your study:

Hazards	**Risks**	**If yes, consider what precautions will be taken to minimise risk and discuss with your Supervisor**
Use of ionising or non-ionising radiation	***NO***	-
Use of hazardous substances	***NO***	-
Use of face-to-face interviews *Interviewees could be upset by interview and become aggressive or violent toward researcher*	***NO***	**-**
Use of face-to-face interviews *Participants or interviewees could become upset by*	***NO***	**-**

interview and suffer psychological effects		
Sensitive data	***NO***	-
Physical activity	*Exposure to levels of exertion unsuitable for an individual's level of fitness* ***YES***	***Consider:*** • *Health Questionnaire / qualified supervision.* • *Trained First Aid personnel/ Equipment.*
Equipment	***NO***	
Sensitive issues i.e. Gender/Cultural e.g. when observing or dealing with undressed members of the opposite sex	***NO***	-
Children	***NO***	-
Manual handling activities	***NO***	-

If you have answered 'YES' to any of the hazards in section 3, then please list the proposed precautions below:

- A detailed health questionnaire and medical declaration will have to be completed before commencing any testing.
- First aid trained personnel will be on hand in the lab when testing is taking place, with first aid equipment within the building.
- During all testing high qualified coaches and researchers will supervise the testing protocol to make sure that safety of all participants is guaranteed priority.
- Prior and post to every testing session all equipment will be checked and maintained as per manufacturer's instructions. With any faults being identified and noted with the lab technicians, Steve Horton and/or Laura Smith.
- When participants attend testing sessions, they will be provided with time to familiarise themselves with all testing protocols.

- Participants will not be undertaking any tasks which they are not familiar with, or which exceed the normal level of exertion that they will be familiar with from training.

Signature of student ……………………………………. Date ……………………….

Signature of Supervisor …………………………………. Date ……………………….

APPENDIX 4

Health Questionnaire and Informed Consent **(Version 1, 15/01/2019)**

Participants Health Questionnaire

Surname : ……………………………   Forename(s) : …………………………......
Date of birth : …………….....................   Age : ……………………….…………………..
Height (cm) : ………………………..…   Weight (kg) : ……………….……………………

2. Additional information

a. Please state when you last had something to eat / drink……………………...
b. circle the statement that relates to your present level of activity:
Inactive   moderately active   highly active
c. Give an example of a typical weeks exercise:
……………………………………………………………………………………………...
d. If you smoke, approximately how many cigarettes do you smoke a day……..

3.	Are you currently taking any medication that might affect your ability to participate in the test as outlined?	YES	NO
4.	Do you suffer, or have you ever suffered from, cardiovascular disorders? e.g. Chest pain, heart trouble, cholesterol etc.	YES	NO
5.	Do you suffer, or have you ever suffered from, high/low blood pressure?	YES	NO
6.	Has your doctor said that you have a condition and that you should only do physical activity recommended by a doctor?	YES	NO
7.	Have you had a cold or feverish illness in the last 2 weeks?	YES	NO

8.	Do you ever lose balance because of dizziness, or do you ever lose consciousness?	YES	NO

9.	Do you suffer, or have you ever suffered from, respiratory disorders? e.g. Asthma, bronchitis etc.	YES	NO
10.	Are you currently receiving advice from a medical advisor i.e. GP or Physiotherapist **not** to participate in physical activity because of back pain or any musculoskeletal (muscle, joint or bone) problems?	YES	NO
11.	Do you suffer, or have you ever suffered from diabetes?	YES	NO
12.	Do you suffer, or have you ever suffered from epilepsy/seizures?	YES	NO
13.	Do you know of any reason, not mentioned above, why you should not exercise? e.g. Head injury (within 12 months), pregnant or new mother, hangover, eye injury or anything else.	YES	NO

INFORMED CONSENT

The full details of the test have been explained to me. I am clear about what will be involved and I am aware of the purpose of the test, the potential benefits and the potential risks.

I know that I am not obliged to complete the test. I am free to stop the test at any point and for any reason.

The test results are confidential and will only be communicated to others once the data is fully anonymized, with no identifiable individual data.

I agree that the data being collected can be used within a research project (circle as appropriate):
Yes No

Signature of Participant : ..…………………………Date : …………………...

Name of Supervisor : ……………………………..

Signature of Supervisor : ………………………….Date : ……………….......

If this questionnaire was not completed and countersigned immediately prior to the test, the subject must complete this section.

I certify that none of the above information has changed since I completed this questionnaire.

Signed : ……..………………………………………Date : …………………...

APPENDIX 5 (Version 1, 15/01/2019)

Dear {insert module leaders name},

I am emailing to enquire about the possibility of attending your lectures, with regards to informing your students of my intended research, titled "**Differences in kinetics and kinematics during weightlifting overhead pressing derivatives across a range of exercise variations and loads**". If it would be possible to give a brief 5-minute presentation to inform them of the rationale behind my study and my chosen methodologies.

After which, I will ask for contact details of interested individuals as well as being able to provide a participant information sheet and answer any further questions that may arise from my presentation.

Please find attached the participant information sheet I intend to distribute to interested individuals. If you require any more information about my project, please do not hesitate to contact myself or my supervisor.

Sincerely,

[redacted]

APPENDIX 6 (Version 1, 15/01/2019)

Weightlifting Overhead Pressing Exercises

The aims of this study are to determine:

- The main differences on kinetics and kinematics across different overhead pressing exercises and variations.
- The impact of load on kinetics and kinematics across different overhead pressing exercises and variations.

Are you **passionate of weightlifting /CrossFit**?

Would you like to **improve your lifts**/ to choose the adequate loads and exercises to continue improving your **performance**?

Do you have **previous experience on Olympic pressing lifts** such as push press, push jerk and split jerk?

Are you **regularly involved in S&C programs** including in: weightlifting, fitness, CrossFit and sports?

Are you **free of any injuries** to perform Olympic lifts?

Please contact:

Researcher	[redacted]
email	[redacted]

APPENDIX 7 (Version 1, 15/01/2019) Organisation Management Consent/Agreement Letter

Dear Terry Surridge; president of *TeamManchester Weightlifting club*,

I am emailing you as the head coach/president of the team Manchester weightlifting club to inquire about the possibility of attending your club, with regards to informing your trainees of my proposed research, titled "Differences in kinetics and kinematics during weightlifting overhead pressing derivatives across a range of exercise variations and loads". I would love to ask you for the possibility of a brief 5-minute presentation to inform them of the rationale behind my study and my chosen methodologies.

My little intention is to establish an agreement between the *team Manchester weightlifting club* and our research team developed at the *University of Salford*. We try to provide information to coaches and practitioners developing exciting researches. However, we cannot develop investigations successfully if we do not count on your help. That is why it is a win/win project, which will be fruitful for all of us.

Please find attached the participant information sheet I intend to distribute to interested individuals. If you require any more information about my project, please do not hesitate to contact myself or my supervisor.

Sincerely,

[redacted]

APPENDIX 8 (Version 1, 15/01/2019) Participant Invitation Letter

Dear participants,

I invite you to be part of my proposed research, titled "Differences in kinetics and kinematics during weightlifting overhead pressing derivatives across a range of exercise variations and loads".

It may be a fascinating experience for you, where you will have the opportunity to contribute to sports science and also to learn from professional researchers. Furthermore, we offer you all the information that you may need and also a complete performance report will be written for each one of you, explaining what should be the orientation of your training to continue improving.

Nonetheless, if you have any kind of problem which may lead to not completing the study at any part of it, feel free to say so. However, if you can help us to contribute to sports science, I strongly encourage you for doing so.

Please find attached the participant information sheet I intend to distribute to interested individuals. If you require any more information about my project, please do not hesitate to contact myself or my supervisor.

Sincerely,

[redacted]