Universitat de València

Facultat de Ciències de la Activitat Física i l'Esport

"MÉTODOS DE ENTRENAMIENTO DE FUERZA ALTERNATIVOS PARA INCREMENTAR LA ACTIVACIÓN MUSCULAR EN EJERCICIOS DE EMPUJE"

TESIS DOCTORAL

Presentada por:
D. Joaquín Calatayud Villalba

Dirigida por:
Dr. D. Juan C. Colado Sánchez
Dr. D. Lars L. Andersen

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POR COMPENDIO DE PUBLICACIONES
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Dr. D. Juan Carlos Colado Sánchez, Profesor Titular de la Universitat de València, adscrito al *Departament de Educació Física i Esportiva* de la Universitat de València.

Dr. D. Lars Louis Andersen, Professor at *National Research Centre for the Working Environment*, Copenhagen (Denmark).

CERTIFICAN:

Que el presente trabajo, titulado "***Métodos de entrenamiento alternativos para incrementar la activación muscular en ejercicios de empuje***" ha sido realizado bajo su dirección en el *Departament d' Eduació Física i Esportiva* de la *Universitat de València y* en "The National Research Centre for the Working Environment" (Copenhague, Dinamarca) por D. Joaquín Calatayud Villalba, para optar al grado de Doctor. Habiéndose concluido, y reuniendo a su juicio las condiciones de originalidad y rigor científico necesarias, autorizan su presentación a fin de que pueda ser defendido ante el tribunal correspondiente.

Y para que así conste, expiden y firman la presente certificación en Valencia, a 2 de Marzo de 2016.

Fdo: Juan C. Colado Sánchez

Fdo: Lars L. Andersen

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"Lo que con mucho trabajo se adquiere, más se ama" (Aristóteles)

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Prefacio

La presente tesis doctoral se llevó a cabo en la Facultad de Ciencias de la Actividad Física y el Deporte de la Universidad de Valencia y en "The National Research Centre for the Working Environment", Copenhague, Dinamarca. Los directores de este trabajo han sido Juan Carlos Colado (Unidad de Investigación en Deporte y Salud de la Universidad de Valencia) y Lars L. Andersen (National Research Centre for the Working Environment, Copenhague, Dinamarca).

Antes de reclutar la muestra, los objetivos, hipótesis y variables a medir fueron predefinidos y aprobados por comités éticos locales (H1355400388327; H-3-2010-062). Todas las condiciones y experimentos aquí descritos respetan la declaración de Helsinki.

ÍNDICE

Índice de abreviaturas

RM: Repetición Máxima

EMG: Electromiografía

ACSM: American College of Sports Medicine

NSCA: National Strength and Conditioning Association

MCVI: Máxima Contracción Voluntaria Isométrica

ANOVA: Analysis of Variance (Análisis de la Varianza)

RMS: Root Mean Square (Valor Cuadrático Medio)

SD: Standard Deviation (Desviación Estándar)

SE: Standard Error (Error Estándar)

Índice de contenidos

Lista de artículos

La presente tesis se basa en la publicación de 4 artículos. Estos serán nombrados a lo largo del texto como “Artículo I-IV”.

Artículo I

Calatayud, J., Borreani, S., Colado, J. C., Martín, F. F., Rogers, M. E., Behm, D. G., & Andersen, L. L. (2014). Muscle Activation during Push-Ups with Different Suspension Training Systems. *Journal of Sports Science & Medicine, 13*(3), 502–510.

Artículo II

Calatayud, J., Borreani, S., Colado, J. C., Martin, F., & Rogers, M. E. (2014). Muscle activity levels in upper-body push exercises with different loads and stability conditions. *The Physician and Sportsmedicine, 42*(4), 106–119.

http://doi.org/10.3810/psm.2014.11.2097

Artículo III

Calatayud, J., Borreani, S., Colado, J. C., Martin, F., Tella, V., & Andersen, L. L. (2015). Bench press and push-up at comparable levels of muscle activity results in similar strength gains. *Journal of Strength and Conditioning Research, 29*(1), 246–253.

http://doi.org/10.1519/JSC.0000000000000589

Artículo IV

Calatayud, J., Vinstrup, J., Jakobsen, M. D., Sundstrup, E., Brandt, M., Jay, K., … Andersen, L. L. (2015). Importance of mind-muscle connection during progressive resistance training. *European Journal of Applied Physiology*, *116*(3), 527–533. http://doi.org/10.1007/s00421-015-3305-7

Resumen

Introducción.

Los movimientos en los que se empuja o presiona con los brazos a una resistencia externa constituyen un elemento clásico dentro de los programas de entrenamiento de la fuerza. Tradicionalmente se han empleado ejercicios convencionales con pesos libres y máquinas con los que se conseguía alcanzar intensidades de activación muscular altas. Sin embargo, tratando de incrementar en mayor medida la intensidad en este tipo de ejercicios, durante los últimos años se han comenzado a utilizar nuevos medios y métodos alternativos (por ejemplo utilizando dispositivos de suspensión, resistencia elástica o tratando de activar músculos de forma selectiva). No obstante, es escasa la evidencia científica que avala dichos recursos materiales y métodos alternativos para incrementar la activación muscular en extremidades superiores y tronco al compararlos con métodos más tradicionales.

Los objetivos de la presente tesis fueron:

1) Comparar la activación muscular al realizar flexiones suspendidas con cuatro elementos de suspensión diferentes (Artículo I).
2) Evaluar la activación muscular durante diferentes variaciones de flexiones de brazos y comparar su activación con la del press de banca y el press polea en bipedestación, ambos realizados al 50%, 70% y 85% de 1 repetición máxima (RM) (Artículo II).
3) Evaluar la activación muscular en 6RM de press de banca y en 6RM de flexiones de brazos en el suelo realizadas con resistencia elástica añadida y a continuación evaluar las ganancias de fuerza tras utilizar un ejercicio u otro (Artículo III).
4) Evaluar si al focalizarse en el pectoral mayor o el tríceps braquial durante el press de banca se puede incrementar la activación de forma selectiva. Se presta especial atención a la relación entre la intensidad del ejercicio y la magnitud de la activación selectiva (Artículo IV).

Métodos.

Para investigar el primer objetivo de la tesis (Artículo I), 29 varones, estudiantes universitarios sanos participaron de manera voluntaria realizando 3 flexiones de brazos con cada uno de los 4 dispositivos de suspensión. La velocidad del ejercicio fue controlada utilizando un metrónomo y el orden de los ejercicios fue aleatorio. Los niveles de activación muscular fueron adquiridos utilizando electromiografía (EMG) en la porción larga del tríceps braquial, trapecio porción superior, porción anterior del deltoides, porción clavicular del pectoral mayor, recto anterior del abdomen, recto femoral y erector lumbar espinal.

Para investigar el segundo objetivo (Artículo II), 29 varones, estudiantes universitarios y sanos participaron de manera voluntaria realizando 3 repeticiones en todas las condiciones bajo los mismos procedimientos estandarizados. Se analizó la señal de EMG de los músculos recto anterior del abdomen, oblícuo externo, porción esternocostal del pectoral mayor, porción anterior del deltoides, porción larga del tríceps braquial, trapecio porción superior, serrato anterior y la porción posterior del deltoides.

Para abordar el tercer objetivo de la presente tesis (Artículo III), 30 estudiantes universitarios con experiencia de entrenamiento de fuerza participaron voluntariamente en un estudio de dos partes. Cada sujeto participó en 16 sesiones diferentes realizadas en el siguiente orden: dos sesiones de familiarización, evaluación de 1RM en el press de banca, dos test de 6RM con evaluación de EMG en la porción esternocostal del pectoral mayor y la porción anterior del deltoides, 10 sesiones de entrenamiento durante 5 semanas (usando las mismas cargas y variables que fueron usadas durante la evaluación EMG), medición de 1RM y 6RM en press de banca.

Por último, un total de 18 adultos hombres con experiencia de entrenamiento de fuerza participaron voluntariamente para evaluar el cuarto objetivo de la tesis (Artículo IV). Los sujetos realizaron 3 repeticiones en 3 diferentes condiciones de press de banca (press de banca tradicional y press de banca tratando de utilizar de forma selectiva los músculos pectoral mayor o tríceps braquial) a intensidades del 20%, 40%, 50%, 60% y 80% de 1RM. Se evaluó la señal de EMG de los músculos mencionados.

Resultados y conclusiones.

En el Artículo I, las flexiones suspendidas con el dispositivo con polea generaron mayor actividad en el tríceps braquial, el trapecio porción superior, el recto femoral y el erector lumbar espinal que el resto de dispositivos de suspensión y que las flexiones tradicionales. El dispositivo con dos anclajes generó mayor activación del pectoral mayor que el resto de dispositivos y las flexiones tradicionales. Sin embargo, las flexiones tradicionales proporcionaron mayor activación muscular de la porción anterior del deltoides que el resto de dispositivos de suspensión, exceptuando el de dos anclajes. Todos los dispositivos de suspensión incrementaron de forma efectiva la activación muscular en el recto anterior del abdomen.

En el Artículo II, las flexiones realizadas con resistencia elástica generaron similar activación muscular en los principales movilizadores que el press de banca realizado a alta intensidad, mientras que generaron mayor activación en la musculatura abdominal. Las flexiones suspendidas fueron muy efectivas para estimular la musculatura abdominal. La activación del pectoral mayor, porción anterior del deltoides y serrato anterior fue mayor durante condiciones más estables, mientras que los músculos del abdomen, el tríceps braquial y la porción posterior del deltoides se activaron más durante los ejercicios realizados en situación de inestabilidad.

En el Artículo III, 6RM en press de banca y 6RM en flexiones con resistencia elástica generaron comparables valores de EMG durante la sesión de evaluación y también provocaron ganancias de fuerza similares después del periodo de intervención, mientras que el grupo control permaneció igual. Así, cuando los niveles de activación muscular son comparables y los ejercicios de empuje sean biomecánicamente y cinemáticamente similares, las ganancias de fuerza serán similares.

En el Artículo IV, sujetos con experiencia de entrenamiento de fuerza fueron capaces de incrementar la activación del tríceps braquial o el pectoral mayor cuando se focalizaban en uno u otro músculo durante el press de banca realizado hasta intensidades del 60% de 1RM. Parece existir un umbral entre 60% y 80% de 1RM.

En conclusión, existen cantidad de alternativas a los métodos convencionales para alcanzar niveles altos de actividad muscular (y por tanto ganancias de fuerza). Ello proporciona un mayor grado de variación en ejercicios para incrementar la fuerza muscular de lo que se pensaba.

Summary (English)

Introduction.

Pushing or pressing movements with the arms against external resistance are classic elements of strength training programs. Traditionally, conventional strength exercises using free weights and machines have been used for achieving high intensities of muscle activity. However, new ways and alternative training methods (e.g. by using suspension training devices, elastic resistance or trying to selectively activate muscles) have increased during recent years. Nevertheless, scientific evidence supporting the use of such training methods and devices to achieve high intensities of upper-body muscle activity is scarce.

The main purposes of this PhD thesis were:

1. To compare muscle activity during suspended push-ups using different suspension training systems (Paper I).
2. To compare muscle activity during push-up variations with the bench press exercise and the standing cable press exercise both performed at 50%, 70%, and 85% of the 1-repetition maximum (Paper II).
3. To compare muscle activity during 6 repetition maximum (6RM) bench press and added-resistance push-up, and subsequently to evaluate the strength gains after a training period with each of these exercises (Paper III).
4. To evaluate whether focusing on using the pectoralis major and triceps brachii muscles, respectively, during bench press can selectively activate these muscles. We were especially interested in measuring the relationship between exercise intensity and the magnitude of selective activation (Paper IV).

Methods.

To investigate the first purpose of the thesis (Paper I), 29 fit male university students voluntarily participated performing 3 push-ups each with 4 different suspension systems. Push-up speed was controlled using a metronome. Testing order was randomized. The level of muscle activity was recorded using electromyography (EMG)

for the triceps brachii, upper trapezius, anterior deltoid, clavicular pectoralis, rectus abdominis, rectus femoris, and lumbar erector spinae.

To investigate the second purpose (Paper II), 29 fit male students voluntarily participated performing 3 repetitions in all conditions under the same standardized procedures. EMG signals were recorded for the rectus abdominis, external oblique, sternocostal head of the pectoralis major, anterior deltoid, long head of the triceps brachii, upper trapezius, anterior serratus and posterior deltoid.

To address the third aim of the present thesis (Paper III), 30 university students with resistance training experience voluntarily participated in a two-part study. Each participant took part in 16 sessions in the following order: two familiarization sessions, a 1RM bench press test session, two 6RM tests with EMG data collection on the sternocostal head of the pectoralis major and anterior deltoid, 10 training sessions during 5 weeks (using the same loads and variables that were used during the EMG data collection), a post-1RM bench press estimation session, and lastly a post-6RM bench press estimation session.

Finally, to evaluate the fourth purpose of this thesis, 18 resistance-trained adult men voluntarily participated. Subjects performed 3 repetitions on 3 different bench press conditions with intensities of 20%, 40%, 50%, 60% and 80% of 1RM: regular bench press, and bench press focusing on selectively using the pectoralis major and triceps brachii, respectively. EMG signals were recorded for the triceps brachii and pectoralis major muscles.

Results and conclusions.

In Paper I, the suspended push-up with a pulley system provided greater triceps brachii, upper trapezius, rectus femoris and lumbar erector spinae muscle activity compared with the other suspension systems and the standard push-up. The two-anchor system provided greater pectoralis major activity than the other systems and the standard push-up. However, the standard push-up provided greater anterior deltoid activity than the other suspension systems except the two-anchor system. All the suspension systems effectively enhanced rectus abdominis activity.

In Paper II, elastic-resisted push-ups induced similar levels of muscle activity the prime movers as the bench press performed at high load while also providing a greater core activity. Suspended push-ups were highly effective to induce high levels of abdominal muscle activity. Muscle activity of the pectoralis major, anterior deltoid and anterior serratus were higher during more stable pushing conditions, whereas abdominal muscles, triceps brachii, posterior deltoid and upper trapezius were more active during the unstable exercises.

In Paper III, the 6RM bench press and the 6RM elastic-resisted push-ups induced comparable levels of muscle activity as assessed by EMG during the baseline session, and provided comparable muscle strength gains after the intervention period, whereas control group remained unchanged. Thus, when the levels of muscle activity are comparable and the kinematics and biomechanics of the push exercises are broadly similar, the gain in muscle strength will be similar.

In Paper IV, resistance-trained participants were able to increase triceps brachii or pectoralis major muscle activity during the bench press when focusing on using either of these specific muscle at intensities up to 60% of 1RM. A threshold between 60% and 80% where selective activity no longer was possible appeared to exist.

In conclusion, several alternatives to conventional methods for reaching high levels of muscle activity – and thus strength gains – appear to exist. This provides a larger degree of variability for exercises to increase muscle strength than previously thought.

INTRODUCCIÓN

1. Introducción

1.1 Importancia del entrenamiento de la fuerza en el rendimiento deportivo y la salud.

El entrenamiento de la fuerza produce una serie de cambios morfológicos y neurológicos que propician no solo la mejora de la fuerza máxima, sino también de la resistencia muscular, la hipertrofia muscular y la potencia muscular (Folland & Williams, 2007). Dichos cambios no se producen solo en personas desentrenadas sino también en atletas, mejorándose la habilidad del salto, el rendimiento en los sprint (Harries, Lubans, & Callister, 2012), la economía de carrera (Beattie, Kenny, Lyons, & Carson, 2014) y por tanto el rendimiento deportivo general (Harries et al., 2012).

A pesar de que el entrenamiento de la fuerza puede parecer una modalidad especialmente destinada a promover adaptaciones favorables para el rendimiento deportivo, los efectos que se producen sobre la salud son innumerables, si bien en ocasiones son menos conocidos. Según el "American College of Sports Medicine" (ACSM), la fuerza y la resistencia muscular (aptitud muscular) son uno de los componentes de la condición física relacionada con la salud (Garber et al., 2011). Ningún medicamento ha demostrado mayor eficiencia que el entrenamiento de fuerza para mantener la aptitud muscular, la cual es un factor clave para asegurar un estilo de vida independiente a lo largo de la vida (Fiuza-Luces, Garatachea, Berger, & Lucia, 2013).

Mayor fuerza muscular está asociada con mejor salud general (Jurca et al., 2005; Pollock et al., 2000), mejores perfiles de los factores de riesgo cardiometabólicos (Jurca et al., 2005), menor riesgo de mortalidad por cualquier causa, incluso después de ajustar factores como la edad, grasa corporal, tabaquismo, alcoholismo o la salud cardiovascular (Volaklis, Halle, & Meisinger, 2015), menor riesgo de enfermedad cardiovascular (Tanasescu et al., 2002; Volaklis, Halle, Koenig, et al., 2015), menor riesgo de desarrollar limitaciones funcionales (Brill, Macera, Davis, Blair, & Gordon, 2000) y menor riesgo de enfermedad no letal (Jurca et al., 2005). La práctica de actividades relacionadas con la mejora de la fuerza muscular previene y produce efectos positivos sobre el síndrome metabólico (Malik et al., 2004) y algunos de sus factores de riesgo asociados, produciendo cambios en la composición corporal (Strasser, Siebert, & Schobersberger, 2010), los niveles de glucosa en sangre (Sigal et al., 2007; Sillanpää et al., 2009), la sensibilidad a la insulina (Klimcakova et al., 2006) y la presión arterial (Sillanpää et al., 2009; Strasser et al., 2010). El entrenamiento de la fuerza produce numerosos efectos positivos en la salud musculoesquelética, como por ejemplo es el aumento de la densidad mineral ósea (Gómez-Cabello, Ara, González-Agüero, Casajús, & Vicente-Rodríguez, 2012; Kohrt et al., 2004), la prevención de la artrosis (Slemenda et al., 1998), la mejora de la funcionalidad y del dolor durante esta enfermedad (Bischoff & Roos, 2003) o la disminución del dolor de cuello y los hombros asociados con el trabajo (Andersen et al., 2011). Este tipo de entrenamiento tiene un impacto positivo en la prevención de algunos tipos de cáncer (Newton & Galvão, 2008), mejorando también la calidad de vida en gente que lo padece (Mishra et al., 2012). Además, recientes investigaciones afirman que el entrenamiento de la fuerza también produce efectos positivos sobre los estados de ansiedad y depresión (Carek, Laibstain, & Carek, 2011).

1.2 Ejercicios de empuje para el entrenamiento de la fuerza.

Dentro de los programas de entrenamiento de fuerza, los ejercicios de empuje constituyen un elemento clásico (Baechle & Earle, 2008; Fleck & Kraemer, 2004). El movimiento de empuje es requerido en la realización de multitud de actividades deportivas (Baechle & Earle, 2008), pero también durante el trabajo (Hoozemans, Knelange, Frings-Dresen, Veeger, & Kuijer, 2014) y durante numerosas tareas cotidianas (McGill, Cannon, & Andersen, 2014) como por ejemplo empujar el carro de la compra o cerrar una puerta.

Sin duda, los ejercicios de empuje más clásicos para mejorar la fuerza muscular en extremidades superiores y tronco son el press de banca y las flexiones de brazos o “push-ups” (Baechle & Earle, 2008; Ratamess, 2011), ambos en su versión estándar, es decir, el press de banca horizontal y con barra y las flexiones de brazos realizadas en el suelo (denominados como press de banca y flexiones de brazos a lo largo de la presente tesis). No obstante, si bien es sabido que el press de banca es un ejercicio óptimo para promover ganancias de fuerza máxima, no existe evidencia acerca de la efectividad de las flexiones de brazos para alcanzar este objetivo, especialmente si se compara con el press de banca. Las flexiones de brazos se han utilizado a lo largo de los años para mejorar el rendimiento muscular de hombros, pecho y brazos (Cogley et al., 2005; Youdas et al., 2010) en diversas poblaciones, incluyendo tanto atletas como niños (Suprak, Dawes, & Stephenson, 2011). Usualmente se han utilizado como parte del calentamiento dinámico y como alternativa a ejercicios que implican levantamiento o manipulación de pesos externos (Suprak et al., 2011). A su vez, este ejercicio es utilizado en importantes baterías de test como las propuestas por el ACSM (American College of Sports Medicine, 2014), la National Strength & Conditioning Association (NSCA) (Baechle & Earle, 2008) o el Army Physical Fitness Test (Knapik et al., 2001), considerándose una prueba que evalúa la resistencia muscular.

Las flexiones de brazos son un ejercicio de cadena cinética cerrada, donde el pectoral mayor y el tríceps braquial son los principales músculos en acción (Gouvali & Boudolos, 2005). Su ejecución en la fase concéntrica requiere de un movimiento combinado de aducción en el hombro y extensión del codo (Cogley et al., 2005). Este ejercicio ha demostrado ser un método efectivo para activar la musculatura de los hombros, brazos y pectoral mayor (Cogley et al., 2005; Gouvali & Boudolos, 2005; Youdas et al., 2010) pero también de la musculatura del core (Beach, Howarth, & Callaghan, 2008; Freeman, Karpowicz, Gray, & McGill, 2006; Juker, McGill, Kropf, & Steffen, 1998).

La popularidad de las flexiones de brazos se debe a varios factores. En primer lugar, no requiere material para su realización (Gouvali & Boudolos, 2005) tal y como pasa en otros ejercicios como el press de banca, pues el ejercicio tradicional de flexiones de brazos se realiza con la carga del propio peso corporal (Blackard, Jensen, & Ebben, 1999), pudiendo por tanto ejecutarse en cualquier parte. En segundo lugar, es un ejercicio con una gran facilidad de aprendizaje, modificación y adaptación a los diferentes niveles de condición física (Gouvali & Boudolos, 2005). De esta manera, a través de sencillas manipulaciones posturales se puede modificar la dificultad del ejercicio (Ratamess, 2011).

La aparición de medios y métodos alternativos a los tradicionales (como por ejemplo la utilización de dispositivos de suspensión, la utilización de resistencia elástica o el incremento de la activación muscular de forma selectiva), conlleva la ineludible necesidad de nuevas investigaciones a fin de comprobar su efectividad para incrementar la activación muscular y promover posibles aumentos de fuerza (Andersen et al., 2010).

1.3 Electromiografía de superficie para evaluar la efectividad de los ejercicios para el entrenamiento de la fuerza.

La EMG de superficie es una técnica no invasiva que permite evaluar el sistema neuromuscular, siendo el instrumento más utilizado para estudiar los niveles de actividad muscular y los patrones de activación durante la realización de ejercicios (Soderberg & Knutson, 2000). La señal de EMG representa la actividad eléctrica generada en las fibras musculares como respuesta a la activación proporcionada por las motoneuronas (Farina, Merletti, & Enoka, 2014). Concretamente, la señal de EMG es una combinación del reclutamiento de unidades motoras, su ratio de estimulación y la sincronización de estos impulsos (Aagaard, 2003; Behm, 1995).

Se ha documentado una relación lineal positiva entre la fuerza isométrica y la EMG, mostrando que un incremento en la EMG muscular está asociado con un aumento de la producción de fuerza, si bien no todos los músculos pueden presentar una linealidad perfecta (Alkner, Tesch, & Berg, 2000; Bigland & Lippold, 1954; Milner-Brown & Stein, 1975; Moritani & deVries, 1978; Thorstensson, Karlsson, Viitasalo, Luhtanen, & Komi, 1976). Respecto a la relación entre EMG y fuerza dinámica, algunos estudios han encontrado una linealidad positiva proporcional aunque en varios casos ésta se ha comportado de forma ligeramente curvilínea en algunos músculos (Andersen et al., 2010; Aratow et al., 1993; Kellis & Baltzopoulos, 1997).

Durante la rehabilitación o el acondicionamiento atlético se recomienda la utilización de ejercicios que provoquen un elevado estímulo neural en las fibras musculares (Andersen et al., 2006; Folland & Williams, 2007; Martuscello et al., 2013). A lo largo de los años se ha asumido que aquellos ejercicios que producen mayor señal de EMG generarán mayores ganancias de fuerza (Andersen et al., 2006; Ayotte, Stetts, Keenan, & Greenway, 2007; Distefano, Blackburn, Marshall, & Padua, 2009; Martuscello et al., 2013). Del mismo modo, se ha asumido que aquellos ejercicios que provocan niveles de activación muscular similares también resultarán en similares ganancias de fuerza (Andersen et al., 2010). Sin embargo, tras realizar un profundo análisis de la literatura científica, se puede reseñar que son necesarios estudios que analicen la activación muscular durante diferentes ejercicios y que comprueben seguidamente los efectos crónicos de éstos con el objetivo de dar mayor validez a la EMG como método de evaluación de la efectividad de ciertos ejercicios para promover ganancias de fuerza.

Los valores de EMG se han considerado un marcador de la intensidad de un determinado ejercicio (Andersen et al., 2006). Se ha afirmado que los ejercicios deben alcanzar niveles de activación muscular del 40% al 60% de la máxima contracción voluntaria isométrica (MCVI) para producir adaptaciones de fuerza (Andersen et al., 2006). Sin embargo, los niveles de activación muscular pueden verse afectados por diferentes factores (Criswell & Cram, 2011; Wahl & Behm, 2008). Además, no se conocen los niveles de activación que son necesarios para inducir diferentes adaptaciones de fuerza. Por tanto, son necesarios datos de activación muscular durante la realización de diferentes ejercicios de empuje que puedan ser comparados con niveles de activación de ejercicios realizados a intensidades propias del entrenamiento de la resistencia muscular, hipertrofia y fuerza máxima. Toda esta información aportará nuevos hallazgos respecto al umbral de activación que se requiere para promover diferentes adaptaciones de la fuerza.

1.4 Formas alternativas para incrementar la activación muscular en extremidades superiores y tronco durante los ejercicios de empuje para el entrenamiento de la fuerza.

1.4.1 Activación muscular durante el entrenamiento de la fuerza con ejercicios de empuje en condiciones de inestabilidad.

El entrenamiento de la fuerza realizado en condiciones que generan inestabilidad durante el movimiento ha sido muy estudiado durante la última década (Behm, Muehlbauer, Kibele, & Granacher, 2015). Uno de los motivos para ello, es que varios autores sugirieron que el entrenamiento de la fuerza unido a una condición de inestabilidad suponía un mayor estímulo para el sistema neuromuscular que aquellos entrenamientos realizados sobre condiciones estables (Behm & Colado, 2012). Otro de los elementos que ha propiciado el creciente interés de la comunidad científica por el entrenamiento de la fuerza en inestabilidad es la transferencia que puede provocar este tipo de entrenamiento a aquellas modalidades deportivas o movimientos que presentan condiciones de cierta inestabilidad (Behm & Anderson, 2006). Anderson & Behm (2005) destacaron la importancia de ser capaz de mantener el equilibrio postural durante la realización de tareas, donde los núcleos articulares deben estabilizarse antes de realizar un movimiento de forma eficiente.

De manera concreta, se puede indicar que diferentes estudios han mostrado que el pectoral mayor y la porción anterior del deltoides no variaron su activación cuando se comparó una versión estable del press de banca con otra inestable como un press de banca sobre Swiss ball ya sea con carga absoluta (Anderson & Behm, 2004; Uribe et al., 2010) o relativa (Goodman, Pearce, Nicholes, Gatt, & Fairweather, 2008). Además, tampoco se han encontrado diferencias de activación en estos músculos al comparar entre un press de banca con barra libre y un press de banca en máquina Smith (Saeterbakken, van den Tillaar, & Fimland, 2011; Schick et al., 2010) o al comparar un press de banca con mancuernas con el mismo ejercicio realizado en máquina Smith con carga relativa (Saeterbakken et al., 2011). Los mismos resultados para el pectoral mayor fueron hallados durante flexiones de brazos sobre un Swiss ball en comparación con la versión estable (Lehman, MacMillan, MacIntyre, Chivers, & Fluter, 2006). Sin embargo, algunos estudios encontraron resultados diferentes, mostrando una cantidad de activación similar en la porción anterior del deltoides pero encontrando que el pectoral mayor se activaba menos en la condición más inestable al realizar un press con cable en bipedestación (Santana, Vera-Garcia, & McGill, 2007) y un press de banca sobre diferentes materiales inestables (Saeterbakken & Fimland, 2013). Por lo que se tiene conocimiento, parece que tan solo un estudio encontró similar cantidad de activación muscular en la porción anterior del deltoides pero con una activación más alta del pectoral mayor durante las flexiones de brazos inestables en comparación con las estables (Freeman et al., 2006). Respecto a la porción anterior del deltoides, hay tres estudios donde la activación de este músculo es mayor durante la condición inestable de un press de banca (Marshall & Murphy, 2006), durante un press vertical (Kohler, Flanagan, & Whiting, 2010) y durante una flexión isométrica a un brazo (de Oliveira, de Morais Carvalho, & de Brum, 2008). A pesar de estos resultados, parece ser que en general, el pectoral mayor y la porción anterior del deltoides se activan menos durante situaciones de gran inestabilidad cuando estos músculos tienen una mayor responsabilidad movilizadora en los ejercicios de empuje (Lehman et al., 2006). Por otra parte, es posible que debido a la disminución de la producción de fuerza durante condiciones inestables (Behm & Colado, 2012), cantidades moderadas de inestabilidad en lugar de excesivas puedan ser más adecuadas para elevar la activación de algunos músculos (Behm, Drinkwater, Willardson, & Cowley, 2010).

Respecto al músculo tríceps braquial, los resultados encontrados en la literatura denotan cierta controversia. Mientras que algunos autores han encontrado mayor activación del tríceps braquial en la versión de flexiones de brazos con condición de inestabilidad (Anderson, Gaetz, Holzmann, & Twist, 2013; Lehman et al., 2006), otros artículos han mostrado una ausencia de diferencias en la activación de este músculo al comparar la versión estable de las flexiones de brazos con la inestable (Freeman et al., 2006) o al comparar entre el press de banca estable e inestable tanto con carga absoluta (Anderson & Behm, 2004) como relativa (Goodman et al., 2008). Por el contrario, dos recientes investigaciones muestran que donde menos se activó el tríceps braquial fue en la condición más inestable del press de banca con cargas relativas (Saeterbakken & Fimland, 2013; Saeterbakken et al., 2011). Teniendo en cuenta que se ha recomendado el empleo de inestabilidades moderadas para el aumento de la activación en algunos músculos (Behm et al., 2010) y que además una alta inestabilidad va en detrimento del levantamiento de mayores cargas (Behm & Colado, 2012; Behm et al., 2015), parece lógico que algunos estudios hayan documentado una mayor activación del tríceps braquial durante condiciones que proporcionan moderada inestabilidad como por ejemplo el press con pesos libres y que a su vez, permiten levantar una carga mayor que las otras condiciones más inestables (Saeterbakken & Fimland, 2013; Saeterbakken et al., 2011). De hecho, en el estudio realizado por Goodman et al. (Goodman et al., 2008), hubo una ausencia de diferencias en la carga levantada durante la condición estable e inestable, lo que podría justificar la falta de diferencias de activación encontradas entre condiciones.

Por otra parte, algunos estudios también han medido la actividad de los músculos antagonistas. Hay autores que no han encontrado diferencias en la activación muscular del bíceps braquial durante un press de banca estable en comparación con un press de banca sobre Swiss ball con la misma carga relativa (Goodman et al., 2008; Saeterbakken & Fimland, 2013) o sobre un "balance cushion" (Saeterbakken & Fimland, 2013). Sin embargo, otros estudios han mostrado diferentes resultados, encontrando por ejemplo una mayor activación del bíceps braquial durante la versión inestable de los push-ups (Freeman et al., 2006), o incluso durante la versión inestable del press de banca (Saeterbakken et al., 2011). No obstante, hay que remarcar que este último estudio consideró como versión inestable del press de banca la realización del ejercicio con mancuernas, las cuales pueden por sí mismas crear un entorno de inestabilidad moderada (Wahl & Behm, 2008). Por tanto, es posible que las flexiones de brazos realizadas sobre balones en el estudio de Freeman et al. (Freeman et al., 2006) y el press de banca con mancuernas en el estudio de Saeterbakken et al. (Saeterbakken et al., 2011) proporcionen una inestabilidad moderada que aumente la activación del bíceps braquial como se ha visto en otros músculos.

Avanzando en este marco conceptual, se debe destacar que parece ser que los ejercicios realizados en condiciones de inestabilidad han sido especialmente estudiados para evaluar la activación en la musculatura del core (Behm et al., 2010). Diversos estudios han demostrado que la condición inestable generaba mayor activación de la musculatura abdominal que la versión estable en ejercicios de empuje como las flexiones de brazos (Anderson et al., 2013; Freeman et al., 2006; Marshall & Murphy, 2005), el press de banca (Anderson & Behm, 2004; Marshall & Murphy, 2006; Norwood, Anderson, Gaetz, & Twist, 2007) o el “push-up plus” (Lehman et al., 2006). Por contra, algunos estudios han reportado similares cantidades de activación del recto anterior del abdomen en condiciones estables e inestables del press de banca (Norwood et al., 2007; Uribe et al., 2010) o el press vertical (Uribe et al., 2010), mientras que otros músculos del core como el erector lumbar espinal o el oblicuo interno sí mostraron mayor activación en las condiciones de mayor inestabilidad (Norwood et al., 2007). Por tanto, parece ser que la musculatura del core en general se activa más durante la realización de ejercicios de empuje sobre condiciones inestables. No obstante, estos estudios utilizaron las mismas cargas absolutas para todas las condiciones, lo que podría limitar los resultados encontrados.

Como se ha visto, existen bastantes estudios que han evaluado la actividad muscular al realizar ejercicios sobre superficies inestables. Sin embargo, pocos son los estudios que han evaluado la EMG durante la utilización de dispositivos de suspensión.

1.4.1.1 Flexiones de brazos en condición de suspensión.

Una de las relativamente nuevas forma de realizar un ejercicio de empuje en condiciones de inestabilidad, es a través de la utilización de un material de suspensión (Beach et al., 2008). El entrenamiento en suspensión permite realizar un ejercicio bajo un entorno inestable con el propio peso corporal aprovechando la gravedad.

A pesar de que existen diferentes elementos de suspensión en el mercado y cada uno tiene unas características propias, todos parten de un elemento común, donde una parte del cuerpo está soportada por dos cintas/cadenas que están a su vez sostenidas por uno o dos puntos de anclaje, mientras que la otra parte del cuerpo está en contacto con el suelo.

La popularidad de los dispositivos de entrenamiento en suspensión ha incrementado en los últimos años y su uso es cada vez más extendido en las salas de entrenamiento (McGill et al., 2014). Sin embargo, las modas no siempre son sinónimo de efectividad (Behm & Colado, 2012), siendo pocos los estudios que se han realizado para analizar la activación muscular durante flexiones suspendidas. Beach et al. (2008), encontraron mayor activación de la musculatura abdominal durante les flexiones de brazos suspendidas en comparación con la versión tradicional del ejercicio. Por otro lado, Snarr & Esco (2013) encontraron mayor activación de los músculos pectoral mayor, tríceps braquial y porción anterior del deltoides durante la versión suspendida de flexiones de brazos. Por el contrario, tres estudios realizados en nuestra unidad de investigación encontraron diferentes resultados, siendo las flexiones tradicionales las que generaban mayor (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014) o similar (Borreani, Calatayud, Colado, Moya-Nájera, et al., 2015) activación en la porción anterior del deltoides en comparación con la versión suspendida y además produciendo la misma activación en el pectoral mayor (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014). Otros músculos como el trapecio superior, el tríceps braquial (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014), multífido lumbar, recto femoral (Borreani, Calatayud, Colado, Moya-Nájera, et al., 2015), erector lumbar espinal y el glúteo mayor (Calatayud et al., 2014) parecen activarse en mayor medida en la versión suspendida del ejercicio, probablemente debido a la mayor necesidad de estabilización en varias articulaciones. De acuerdo con nuestros resultados, De Mey et al. (2014) encontraron que durante media flexión de brazos, la versión suspendida provocaba mayor actividad en el trapecio porción superior que la tradicional. Sin embargo, a diferencia de nuestros hallazgos, estos autores reportaron igual o incluso mayor activación del serrato anterior durante medias flexiones de brazos y flexiones con apoyo de rodillas respectivamente. No obstante, los resultados del estudio realizado por De Mey et al. (2014) deben interpretarse con cautela, puesto que los ejercicios aplicados fueron variaciones de las flexiones de brazos. Otro estudio donde se midió la EMG durante flexiones suspendidas es el realizado por McGill et al. (2014), aunque la posibilidad de establecer comparaciones y conclusiones con este estudio es limitada ya que los autores no incluyeron datos sobre las diferencias de activación muscular entre ejercicios (excepto para el serrato anterior). A pesar de ello, estos autores encontraron que el serrato anterior se activaba más durante la condición estable. De forma contraria, la versión suspendida generó valores numéricos de más del doble en el trapecio porción superior y el recto anterior del abdomen que durante la versión tradicional. Respecto a la comparación de otros músculos, esta queda menos clara por la falta de datos reportados en este artículo.

Es importante remarcar que los estudios realizados hasta la fecha tan solo han comparado entre un tipo de dispositivo de suspensión y la versión estable del ejercicio. Por tanto, no hay artículos publicados donde se evalúen diferentes sistemas de suspensión (como por ejemplo sistemas en forma de V con un punto de anclaje, sistemas en forma de V con polea que permiten movimiento unilateral o sistemas de bandas paralelas con dos puntos de anclaje). Se podría especular que la utilización de diferentes tipos de dispositivos de suspensión podría implicar la producción de diferentes niveles de estabilidad y por tanto diferentes patrones y niveles de activación en varios músculos. Además, cabe remarcar que la comparación de las flexiones suspendidas con otros ejercicios de empuje tradicionales como por ejemplo el press de banca es necesaria para conocer su verdadera efectividad a la hora de incrementar la actividad muscular en comparación con otras alternativas.

1.4.2 Activación muscular durante la realización de ejercicios de empuje con resistencia elástica.

Como se ha mostrado, es notable la cantidad de estudios que comprueban la efectividad del entrenamiento de la fuerza en condiciones de inestabilidad. Sin embargo, es escaso el número de investigaciones que comparan la efectividad de la resistencia elástica con pesos libres o máquinas para incrementar la activación muscular en extremidades superiores y tronco.

A diferencia de los pesos libres, las bandas elásticas proporcionan una variación de la carga a lo largo del rango de movimiento de un ejercicio, generando mayor tensión cuanto más se elonga el material (Frost, Cronin, & Newton, 2010). Además, debido a sus propiedades elásticas, estos materiales pueden generar mayores aceleraciones excéntricas que los pesos libres si la velocidad no es controlada (Frost et al., 2010).

Los ejercicios realizados con bandas elásticas han demostrado generar una activación comparable a los pesos libres en diferentes músculos de las extremidades superiores y tronco como la porción media del esplenio de la cabeza, trapecio superior, porción media del deltoides, infraespinoso y el extensor común de los dedos (Andersen et al., 2010) o el bíceps braquial (Aboodarda, Hamid, Muhamed, Ibrahim, & Thompson, 2013). Del mismo modo, un reciente estudio ha encontrado valores comparables de EMG en el recto anterior del abdomen, el oblicuo externo derecho y erector espinal lumbar izquierdo durante el ejercicio de "torso-twist" realizado de izquierda a derecha con resistencia elástica o máquina (Vinstrup et al., 2015). Respecto a musculatura de las extremidades inferiores, diversos estudios han encontrado comparables niveles de EMG al realizar con y sin resistencia elástica ejercicios como zancadas o "lunge" (Jakobsen, Sundstrup, Andersen, Aagaard, & Andersen, 2013), la extensión de rodilla (Jakobsen et al., 2012) y la flexión de rodilla (Jakobsen et al., 2014).

Como se ha dicho previamente, las flexiones de brazos suelen realizarse con el propio peso y por tanto, la intensidad que representan para una persona se ve condicionada y limitada, especialmente en gente entrenada. En este caso, se podría especular que la utilización de bandas elásticas como resistencia externa añadida a las flexiones de brazos, podría suponer una forma sencilla de potenciar la utilidad y efectividad de este ejercicio para promover ganancias de fuerza máxima e hipertrofia, aún en gente entrenada. El uso de resistencia elástica ha demostrado ser efectivo para producir similares ganancias de fuerza que los pesos libres y máquinas en mujeres jóvenes y activas (Colado et al., 2010) y en mujeres sedentarias de mediana edad (Colado & Triplett, 2008). Sin embargo, hay que destacar la ausencia de estudios que hayan evaluado el uso de la resistencia elástica durante la realización de flexiones de brazos, tanto con referencia a sus posibles efectos agudos como a los crónicos.

1.4.3 Activación muscular selectiva durante la realización de ejercicios de empuje.

Durante años se han utilizado diferentes métodos para proporcionar información en tiempo real y poder controlar de forma voluntaria la activación muscular (Giggins, Persson, & Caulfield, 2013; Palmerud, Sporrong, Herberts, & Kadefors, 1998). Por ejemplo, la señal de EMG puede ser utilizada a modo de biofeedback para ayudar a manipular la intensidad durante contracciones musculares (Holtermann et al., 2009; Holtermann, Mork, Andersen, Olsen, & Søgaard, 2010; Palmerud et al., 1998), algo que ha sido especialmente utilizado en programas de rehabilitación neurológica y musculoesquelética (Giggins et al., 2013). Sin embargo, el uso de biofeedback durante el entrenamiento está muy limitado pues requiere de grandes costes en equipamiento y gran experiencia para su utilización. En cambio, una simple información o instrucción verbal por parte del entrenador puede producir cambios en la eficiencia de un ejercicio a través de modificaciones de la técnica (Cowling, Steele, & McNair, 2003) o a través de focalizarse en utilizar o contraer unos músculos específicos (Snyder & Fry, 2012). En este sentido, se ha afirmado que una focalización en un músculo concreto (en lugar de focalizarse en el efecto de una acción) incrementa la activación muscular debido a una menor economía en el movimiento (McNevin & Wulf, 2002).

En función de todos estos argumentos expuestos, el ACSM considera que el tratar de contraer al máximo un músculo de forma voluntaria es una forma de crear auto-resistencia durante el entrenamiento de fuerza (Ratamess, 2011). Esta práctica ha sido utilizada tradicionalmente por los culturistas, a pesar de que no existen muchos estudios que corroboren la efectividad de dicho método. Instrucciones verbales concretas han demostrado tener efectos positivos tanto en acciones musculares dinámicas como isométricas. Por ejemplo, un estudio (Sahaly, Vandewalle, Driss, & Monod, 2003) encontró que dependiendo de las instrucciones, la señal de EMG incrementaba o disminuía durante una flexión de codo isométrica o extensiones de rodilla isométricas realizadas unilateral y bilateralmente. Sin embargo, tan solo un estudio analizó el efecto de la activación selectiva en uno de los ejercicios clásicos de empuje. Snyder & Fry (2012) encontraron que los sujetos podían incrementar la activación en los principales movilizadores después de recibir instrucciones para activar de forma selectiva uno u otro músculo durante el press de banca al 50% de la 1RM. Así pues, las instrucciones para activar el pectoral incrementaron un 22% la activación del pectoral mayor mientras que la activación del tríceps braquial aumentó un 26% en comparación con la condición estándar. No obstante, al realizar el ejercicio a mayor intensidad (80% de la 1RM), tan solo las instrucciones para activar el pectoral tuvieron un efecto positivo en la señal de EMG, causando un aumento de la activación en el pectoral mayor y la porción anterior del deltoides. En la misma línea, los resultados de otros estudios (a pesar de utilizar distinta musculatura y ejercicios) sugieren que es posible incrementar la activación de forma selectiva cuando las intensidades son bajas, tal y como se ha visto en el ejercicio de “curl” de tronco (Karst & Willett, 2004), en la maniobra de “abdominal hollowing” (Critchley, 2002), o durante una sentadilla realizada al 50% de la 1RM (Bressel, Willardson, Thompson, & Fontana, 2009). Todos estos resultados remarcan la necesidad de evaluar un rango más amplio de intensidades a fin de comprobar la relación entre éstas y la magnitud de la activación selectiva.

1.5 Objetivos e hipótesis.

Artículo I

Objetivo: comparar la activación muscular al realizar flexiones suspendidas con cuatro elementos de suspensión diferentes.

Hipótesis: el dispositivo de suspensión con polea produciría la mayor activación en todos los músculos excepto en el pectoral mayor y la porción anterior del deltoides, donde no habría diferencias entre las condiciones inestables y la estable.

Artículo II

Objetivo: Evaluar la activación muscular durante diferentes variaciones de flexiones de brazos y comparar su activación con la del press de banca y el press polea en bipedestación, ambos realizados al 50%, 70% y 85% de 1RM

Hipótesis:

1) Las flexiones suspendidas producirían mayor activación en la musculatura abdominal que el resto de condiciones.

2) Las flexiones con banda elástica producirían niveles de EMG similares al press de banca realizado al 70% de 1RM.

3) El press de banca produciría mayor activación que el press polea a la misma intensidad relativa.

Artículo III

Objetivo: Evaluar la activación muscular en 6RM de press de banca y en 6RM de flexiones de brazos en el suelo realizadas con resistencia elástica añadida y a continuación evaluar las ganancias de fuerza tras utilizar un ejercicio u otro.

Hipótesis: las 6RM en flexiones de brazos y las 6RM en press de banca producirían similares niveles de EMG y similares ganancias de fuerza muscular después del programa de entrenamiento.

Artículo IV

Objetivo: evaluar si al focalizarse en el pectoral mayor o el tríceps braquial durante el press de banca se puede incrementar la activación de forma selectiva. Se presta especial atención a la relación entre la intensidad del ejercicio y la magnitud de la activación selectiva.

Hipótesis: la habilidad para activar selectivamente los músculos decrecería con el aumento de las intensidades.

METODOLOGÍA

2. Metodología

La metodología aplicada en los estudios que componen la presente tesis se explica detalladamente en los artículos originales. Los datos más relevantes serán descritos en esta sección. La siguiente tabla (Tabla 1) proporciona un esquema de la metodología empleada en cada artículo.

Tabla 1. Esquema de la metodología empleada y datos demográficos (Artículos I-IV).

Artículo	Diseño	Sujetos	Variables estudiadas
I	Estudio de medidas repetidas	29 hombres Edad: 24± 3 años Altura: 178.2 ± 0.1 cm Peso: 75.2 ± 8.5 Kg % Graso: 10 ± 3	EMG
II	Estudio de medidas repetidas	29 hombres Edad: 23 ± 3 años Altura: 176.0 ± 4.4 cm Peso: 74.6 ± 6.7 Kg % Graso: 11 ± 3 1RM: 91.6 ± 13.7 Kg	EMG
III	Parte uno: estudio de medidas repetidas Parte dos: intervención (ensayo clínico aleatorizado)	22 hombres 8 mujeres Edad: 22± 3 años Altura: 172.8 ± 7.6 cm Peso: 70.6 ± 8.9 % Graso: 14 ± 6 1RM: 67.3 ± 20.9 Kg	EMG, fuerza muscular (test 1RM y test 6RM)
IV	Estudio de medidas repetidas	18 hombres Edad: 31 ± 8 años Altura: 179.0 ± 8 cm Peso: 82 ± 10 Kg % Graso: 15 ± 5 1RM: 103 ± 25 Kg	EMG

Los valores se reportan como media ± SD
RM: repetición máxima
EMG: electromiografía

2.1 Artículo I (Activación muscular al realizar flexiones suspendidas con cuatro elementos de suspensión diferentes).

2.1.1 Sujetos.

Un total de 29 estudiantes universitarios sanos participaron en el estudio. Los participantes tenían una experiencia en el entrenamiento de fuerza de al menos 1 año, realizando como mínimo 2 sesiones de entrenamiento a la semana y con una experiencia mínima de entrenamiento con dispositivos de suspensión de 4 meses. Ningún sujeto incluido en el estudio presentaba dolor musculoesquelético, trastornos neuromusculares, lesiones óseas o articulares.

El número de participantes fue calculado mediante el software G*Power (Universidad de Kiel, Alemania) y se basó en un tamaño de efecto de 0.25 SD para f y 0.50 SD para d, con un nivel α de 0.05 y una potencia de 0.80.

2.1.2 Procedimientos experimentales.

Cada sujeto participó en 1 sesión de familiarización y 1 sesión experimental con evaluación de EMG, ambas realizadas a la misma hora durante la mañana y con 48-72 horas de separación entre ellas.

2.1.2.a Sesión de familiarización.

En primer lugar se midió la altura (IP0955, Invicta Plastics Limited, Leicester, England), el peso, el porcentaje graso (Tanita model BF- 350, Tokio, Japón) y la distancia biacromial de cada sujeto. A continuación, los sujetos practicaron las diferentes condiciones con la misma técnica y pautas que se iban a utilizar durante la sesión de recolecta de datos. Para ello, los sujetos practicaron los ejercicios hasta que el investigador comprobaba que la ejecución era la adecuada.

2.1.2.b Sesión experimental.

La sesión comenzó con la preparación de la piel para la colocación de los electrodos. Para ello se rasuró con una cuchilla todo el vello que recubría los músculos de interés, se limpió la piel frotando con un algodón humedecido en alcohol y se esperó hasta que esta se secara (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Posteriormente, se colocaron los electrodos en el lado dominante del cuerpo de los músculos tríceps braquial (porción larga), trapecio superior, porción anterior del deltoides, porción clavicular del pectoral mayor, recto anterior del abdomen, recto femoral y erector lumbar espinal, siguiendo recomendaciones establecidas (Criswell & Cram, 2011). Se utilizaron electrodos autoadhesivos bipolares con gel (Blue Sensor M-00-S, Medicotest, Olstykke, Dinamarca) de 10 mm de diámetro en su parte activa. La distancia interelectrodos fue de 25 mm y el electrodo de referencia se situó a unos 10 cm del músculo, tal y como especifica el fabricante.

Una vez colocados los electrodos, los sujetos realizaron dos flexiones de brazos en el suelo para comprobar la señal de EMG, adquirida con un electromiógrafo ME6000P8 biosignal conditioner (Mega Electronics, Ltd., Kuopio, Finland). Todas las señales fueron adquiridas con una frecuencia de 1kHz, amplificadas y convertidas de analógicas a digitales. Todos los registros de activación mioeléctrica (en microvoltios) fueron almacenados en un disco duro para su posterior análisis.

A continuación, cada sujeto realizó 2 MCVIs para cada uno de los músculos a medir, seleccionando el intento con mayor señal de EMG (Jakobsen et al., 2013). Durante las MCVIs se animó a los sujetos para que produjeran la máxima fuerza posible y se permitió un minuto de descanso entre ambas contracciones. Las posiciones de las MCVIs se realizaron de acuerdo a procedimientos descritos en la literatura para evaluar el tríceps braquial (Kendall & Kendall, 2005), el pectoral mayor (Snyder & Fry, 2012), trapecio porción superior (Ekstrom, Soderberg, & Donatelli, 2005), porción anterior del deltoides (Ekstrom et al., 2005), recto anterior del abdomen (Vera-Garcia, Moreside, & McGill, 2010), recto femoral (Jakobsen et al., 2013) y erector lumbar espinal (Jakobsen et al., 2013). Las MCVIs se realizaron contra una resistencia fija (la barra de la máquina Smith).

Los participantes realizaron el ejercicio de flexiones de brazos partiendo desde una posición con los brazos extendidos, los antebrazos en pronación y los pies separados a la anchura biacromial. En la posición baja, los antebrazos se mantuvieron pronados, mientras que el codo fue flexionado 90° y el hombro abducido 45°. Cada participante utilizó una anchura de agarre estandarizada equivalente al 150% de la distancia biacromial. La cadera y la columna vertebral se mantuvieron en posición neutra. Durante las flexiones suspendidas, los mangos de los dispositivos de suspensión estaban situados a una altura de 10 cm respecto al suelo (midiéndose previamente y ajustando la longitud de las bandas para todos los dispositivos). Los sujetos realizaron 5 condiciones diferentes: (a) TRX Suspension Trainer TM (TRX®, San Francisco, CA, EEUU), (b) Jungle Gym XT (LifelineUSA®, Madison, WI, EEUU), (c) Flying (Sidea, Cesea, Italia), (d) AirFit Trainer Pro (PurMotion™, Pelham, AL, EEUU) y (e) flexiones estándar en el suelo. Cada participante realizó 3 repeticiones consecutivas con cada material para evitar la influencia de la fatiga en el siguiente ejercicio (Jakobsen et al., 2013). El orden de realización de las diferentes condiciones fue aleatorio, con un intervalo de 2 minutos de descanso entre condiciones. Se estandarizó la velocidad de ejecución del ejercicio, dándose 4 segundos (2 en la fase excéntrica y 2 en la concéntrica) para realizar el movimiento completo, manteniendo un metrónomo a dicha velocidad.

2.1.3 Análisis de datos.

Las señales de EMG fueron analizadas utilizando el programa Matlab 7.0 (Mathworks Inc, Natick, MA, EEUU). Todas las señales fueron filtradas con un pasabandas de corte de frecuencia a 20-400Hz con un filtro Butterworth de cuarto orden. La amplitud de la señal de la EMG en el dominio del tiempo fue cuantificada utilizando los valores cuadráticos medios (RMS) y procesada cada 100 milisegundos. Se determinaron los valores de la media RMS para cada ejercicio y se normalizaron con el máximo de EMG de cada músculo (%MCVI). Una media de %MCVIs global de todos los músculos también fue calculada y analizada. Para normalizar las señales de EMG se utilizaron los 3 segundos medios de los 5 segundos de la MCVI. Durante los ejercicios dinámicos, el valor promedio de las 3 repeticiones realizadas en cada condición fue seleccionado para analizar la señal de EMG.

2.1.4 Análisis estadístico.

Para realizar el análisis estadístico se usó el software SPSS 17 para Windows (SPSS Inc., Chicago, IL, EEUU). Se comprobó que las variables mostraban una distribución normal (test de Shapiro-Wilk) antes de analizar los datos. Las comparaciones estadísticas entre músculos en cada una de las condiciones se realizaron a través de un análisis de varianza (ANOVA) de medidas repetidas. Se usó una corrección de Greenhouse-Geisser cuando la esfericidad (test de Mauchly) fue violada. En caso de detectarse un efecto principal significativo se utilizó un Post hoc con corrección de Bonferroni. El nivel de significancia se fijó a $p \leq 0.05$.

2.2 Artículo II (Activación muscular durante diferentes variaciones de flexiones de brazos y de press de banca y con polea en bipedestación, ambos realizados al 50%, 70% y 85% de 1RM).

2.2.1 Sujetos.

Un total de 29 estudiantes universitarios sanos participaron en el estudio. Los participantes tenían una experiencia de al menos 1 año en el entrenamiento de la fuerza, realizando 3 sesiones o más por semana a intensidades moderadas-altas. Ningún sujeto incluido en el estudio presentaba dolor musculoesquelético, trastornos neuromusculares, lesiones óseas o articulares.

El número de participantes fue calculado mediante el software G*Power (Universidad de Kiel, Alemania) y se basó en un tamaño de efecto de 0.25 SD para f y 0.50 SD para d, con un nivel α de 0.05 y una potencia de 0.80.

2.2.2 Procedimientos experimentales.

Cada sujeto participó en 4 sesiones diferentes: una de familiarización, dos de cálculo de 1RM y una sesión experimental con evaluación de EMG, realizadas a la misma hora durante la mañana y con 48 horas de separación entre ellas.

2.2.2.a Sesión de familiarización.

En primer lugar se midió la altura (IP0955, Invicta Plastics Limited, Leicester, England), el peso, el porcentaje graso (Tanita model BF- 350, Tokio, Japón) y la distancia biacromial de cada sujeto. A continuación, los sujetos practicaron las diferentes condiciones con la misma técnica y pautas que se iban a utilizar durante la sesión de recolecta de datos. Para ello, los sujetos practicaron los ejercicios hasta que el investigador comprobaba que la ejecución era la adecuada.

2.2.2.b Sesiones de estimación de 1RM.

Dos sesiones de estimación de 1RM (press de banca y press polea en bipedestación) se realizaron con 2 días de separación entre ellas y en orden contrabalanceado. Los sujetos comenzaban la prueba después de realizar el calentamiento, aumentando la carga y el tiempo de descanso entre series de forma progresiva para determinar su 1RM en 3-5 intentos, tal y como determina el protocolo de la NSCA (Baechle & Earle, 2008). En ambos test, los sujetos realizaron el movimiento de press con el codo flexionado a 90° y el hombro abducido a 45°, con una anchura de agarre estandarizada equivalente al 150% de la distancia biacromial. La estimación de 1RM en press de banca se realizó en una máquina Smith mientras que la prueba de 1RM en el press polea se realizó en bipedestación, con los pies situados a una distancia de la máquina de 60 cm, pies en posición paralela y separados a una distancia entre ellos equivalente a la distancia de hombros. En esta última prueba, ninguna parte del cuerpo a excepción de los brazos podía sobrepasar los pies. La determinación de la 1RM permitió calcular las cargas a utilizar (50%, 70% y 85% de 1RM) en estos ejercicios durante la sesión experimental.

2.2.2.c Sesión experimental.

La sesión comenzó con la preparación de la piel para la colocación de los electrodos. Para ello se rasuró con una cuchilla todo el vello que recubría los músculos de interés, se limpió la piel frotando con un algodón humedecido en alcohol y se esperó hasta que esta se secara (Hermens et al., 2000). Posteriormente, se colocaron los electrodos en el lado dominante del cuerpo del recto anterior del abdomen, oblicuo externo, pectoral mayor porción esternocostal, porción anterior del deltoides, porción larga del tríceps braquial, porción superior del trapecio, serrato anterior y porción posterior del deltoides, siguiendo recomendaciones establecidas (Criswell & Cram, 2011). Se utilizaron electrodos autoadhesivos bipolares con gel (Blue Sensor M-00-S, Medicotest, Olstykke, Dinamarca) de 10 mm de diámetro en su parte activa. La distancia interelectrodos fue de 25 mm y el electrodo de referencia se situó a unos 10 cm del músculo, tal y como especifica el fabricante. Una vez colocados los electrodos, los sujetos realizaron una flexión de brazos en el suelo para comprobar la señal de EMG, adquirida con un electromiógrafo ME6000P8 biosignal conditioner (Mega Electronics, Ltd., Kuopio, Finland). Todas las señales fueron adquiridas con una frecuencia de 1kHz, amplificadas y convertidas de analógicas a digitales. Todos los registros de activación mioeléctrica (en microvoltios) fueron almacenados en un disco duro para su posterior análisis.

A continuación, cada sujeto realizó dos MCVIs para cada uno de los músculos a medir, seleccionando el intento con mayor señal de EMG (Jakobsen et al., 2013). Durante las MCVIs se animó a los sujetos para que produjeran la máxima fuerza posible y se permitió 1 minuto de descanso entre ambas contracciones. Las posiciones de las MCVIs se realizaron de acuerdo a procedimientos descritos en la literatura para evaluar el recto anterior del abdomen (Vera-Garcia et al., 2010), oblicuo externo (Vera-Garcia et al., 2010), pectoral mayor (Snyder & Fry, 2012), porción anterior del deltoides (Ekstrom et al., 2005), tríceps braquial (Kendall & Kendall, 2005), trapecio porción superior (Ekstrom et al., 2005), serrato anterior (Ekstrom et al., 2005) y deltoides porción posterior (Kendall & Kendall, 2005). Las MCVIs se realizaron contra una resistencia fija (la barra de la máquina Smith).

Los participantes empezaron los ejercicios partiendo desde una posición con los brazos extendidos, los antebrazos en pronación y los pies separados a la anchura de biacromial. En la posición baja, los antebrazos se mantuvieron pronados, mientras que el codo fue flexionado 90° y el hombro abducido 45°. Cada participante utilizó una anchura de agarre estandarizada equivalente al 150% de la distancia biacromial. La cadera y la columna se mantuvieron en posición neutra.

Los sujetos realizaron 11 condiciones diferentes en orden aleatorio, con 2 minutos de descanso entre ellas: flexiones de brazos suspendidas con un sistema de suspensión en "V" (TRX Suspension Trainer, TRX, San Francisco, CA, EEUU), flexiones suspendidas con el dispositivo anterior pero sin input visual, flexiones de brazos suspendidas con un sistema de suspensión en "V" con polea (AirFit Trainer Pro, PurMotion, Pelham, AL, EEUU), flexiones estándar en el suelo, flexiones en el suelo con resistencia elástica y press de banca en máquina Smith y press polea en bipedestación al 50%, 70% y 85% de 1RM.

En las flexiones de brazos con resistencia elástica, se utilizó una banda elástica de resistencia “Gold” (Thera-band, Hygenic Corporation, Akron, OH, EEUU). Para proporcionar mayor resistencia, se emplearon 70 cm de la longitud total de la banda para realizar el ejercicio. El investigador ayudaba a colocar la banda con dicha longitud por detrás de la espalda a la altura de las escápulas y a continuación, el sujeto extendía la banda para realizar el ejercicio con la amplitud de agarre adecuado (150% de distancia biacromial). Respecto a los dos ejercicios de press, se realizaron con la misma técnica utilizada durante la estimación de 1RM. Por su parte, durante las flexiones suspendidas, las manos y los pies estaban elevados a una altura de 10 cm respecto al suelo. Cada participante realizó 3 repeticiones consecutivas en cada condición para evitar la influencia de la fatiga en el siguiente ejercicio (Jakobsen et al., 2013), con 2 minutos de descanso entre condiciones. La velocidad de ejecución fue de 4 segundos (2 en la fase excéntrica y 2 en la concéntrica) para realizar el movimiento completo, manteniendo un metrónomo a dicha velocidad.

2.2.3 Análisis de datos.

Las señales de EMG fueron analizadas utilizando el programa Matlab 7.0 (Mathworks Inc, Natick, MA, EEUU). Todas las señales fueron filtradas con un pasabandas de corte de frecuencia a 20-400Hz con un filtro Butterworth de cuarto orden. La amplitud de la señal de la EMG en el dominio del tiempo fue cuantificada utilizando RMS, procesada cada 100 milisegundos. Se determinaron los valores de la media RMS para cada ejercicio y se normalizaron con el máximo de EMG de cada músculo (%MCVI). Así mismo, la media global de todos los músculos fue también calculada y analizada. Para normalizar las señales de EMG se utilizaron los 3 segundos medios de los 5 segundos de la MCVI. Durante los ejercicios dinámicos, el valor promedio de las 3 repeticiones realizadas en cada condición fue seleccionado para analizar la señal de EMG.

2.2.4 Análisis estadístico.

Para realizar el análisis estadístico se usó el software SPSS 17 para Windows (SPSS Inc., Chicago, IL, EEUU). Se comprobó que las variables mostraban una distribución normal (test de Shapiro-Wilk) antes de analizar los datos. Las comparaciones estadísticas entre músculos en cada una de las condiciones se realizaron a través de un ANOVA de medidas repetidas. Se usó una corrección de Greenhouse-Geisser cuando la esfericidad (test de Mauchly) fue violada. En caso de detectarse un efecto principal significativo se utilizó un Post hoc con corrección de Bonferroni. El nivel de significancia se fijó a $p \leq 0.05$.

2.3 Artículo III (Respuestas agudas en la activación muscular durante 6RM de press de banca y 6RM de flexiones de brazos con resistencia elástica y respuestas crónicas en las ganancias de fuerza tras utilizar un ejercicio u otro con dicha intensidad).

2.3.1 Sujetos.

Un total de 30 estudiantes universitarios sanos participaron en el estudio. Los participantes tenían una experiencia de al menos un año en el entrenamiento de la fuerza, realizando 3 sesiones o más por semana a intensidades moderadas-altas. Ningún sujeto incluido en el estudio tomaba sustancias que pudieran influir en los resultados, ni presentaba dolor musculoesquelético, trastornos neuromusculares, lesiones óseas o articulares.

2.3.2 Procedimientos experimentales.

Cada sujeto participó en 16 sesiones diferentes, con dos días de separación entre ellas y realizadas en el siguiente orden: dos sesiones de familiarización, evaluación de 1RM en el press de banca, una sesión con dos test de 6RM con evaluación de EMG, 10 sesiones de entrenamiento, una medición de 1RM y por último una medición de 6RM en press de banca. Durante el periodo de entrenamiento, todos los sujetos fueron instruidos para mantener su dieta y actividades deportivas habituales, evitando cualquier cambio en estas que pudiera influir en los resultados.

2.3.2.a Sesiones de familiarización.

En la primera sesión de familiarización se midió la altura (IP0955, Invicta Plastics Limited, Leicester, England), el peso, el porcentaje graso (Tanita model BF- 350, Tokio, Japón) y la distancia biacromial de cada sujeto. En ambas sesiones los sujetos practicaron las diferentes condiciones con la misma técnica y pautas que se iban a utilizar durante la sesión de recolecta de datos. Para ello, se practicaron los ejercicios hasta que el investigador comprobaba que la ejecución era la adecuada.

2.3.2.b Sesión de estimación de 1RM.

Los sujetos comenzaban la prueba después de realizar el calentamiento, aumentando la carga y el tiempo de descanso entre series de forma progresiva para determinar su 1RM en 3-5 intentos, tal y como determina el protocolo de la NSCA (Baechle & Earle, 2008). La estimación de 1RM en press de banca se llevo a cabo en una máquina Smith. Los sujetos realizaron el movimiento con la misma técnica que se iba a utilizar en todas las sesiones. En la posición baja, los antebrazos se mantuvieron en pronación, mientras que el codo fue flexionado 90° y el hombro abducido 45°. Cada participante utilizó una anchura de agarre estandarizada equivalente al 150% de la distancia biacromial y la cadera y la columna se mantuvieron en posición neutra.

2.3.2.c Estimación de 6RM y evaluación de EMG.

La sesión comenzó con un calentamiento y seguidamente se comenzó con la preparación de la piel para colocar los electrodos. Para ello se rasuró con una cuchilla todo el vello que recubría los músculos de interés, se limpió la piel frotando con un algodón humedecido en alcohol y se esperó hasta que esta se secara (Hermens et al., 2000). Posteriormente, en el lado dominante del cuerpo se colocaron los electrodos en el pectoral mayor y la porción anterior del deltoides, siguiendo recomendaciones establecidas (Criswell & Cram, 2011). Se utilizaron electrodos autoadhesivos bipolares con gel (Blue Sensor M-00-S, Medicotest, Olstykke, Dinamarca) de 10 mm de diámetro en su parte activa. La distancia interelectrodos fue de 25 mm y el electrodo de referencia se situó a unos 10 cm del músculo, tal y como especifica el fabricante.

Una vez colocados los electrodos, los sujetos realizaron una flexión de brazos en el suelo para comprobar la señal de EMG, adquirida con un electromiógrafo ME6000P8 biosignal conditioner (Mega Electronics, Ltd., Kuopio, Finland). Todas las señales fueron adquiridas con una frecuencia de 1kHz, amplificadas y convertidas de analógicas a digitales. Todos los registros de activación mioeléctrica (en microvoltios) fueron almacenados en un disco duro para su posterior análisis.

A continuación, cada sujeto realizó dos MCVIs para cada uno de los músculos a medir, seleccionando el intento con mayor señal de EMG (Jakobsen et al., 2013). Durante las MCVIs se animó a los sujetos para que produjeran la máxima fuerza posible y se permitió 1 minuto de descanso entre pruebas. Las posiciones de las MCVIs se realizaron de acuerdo a procedimientos descritos en la literatura para evaluar el pectoral mayor (Snyder & Fry, 2012) y la porción anterior del deltoides (Ekstrom et al., 2005). Las MCVIs fueron realizadas contra una resistencia fija (la barra de la máquina Smith).

Al finalizar las MCVIs, los sujetos descansaron durante 3 minutos y seguidamente fueron asignados de forma contrabalanceada al test de 6RM en flexiones de brazos con resistencia elástica o al de 6RM en press de banca en la máquina Smith. Ambos test se realizaron separados por 10 minutos de descanso. Los participantes empezaron los dos test partiendo desde una posición con los brazos extendidos, los antebrazos en pronación y los pies separados a la anchura biacromial. La técnica empleada fue la misma que se utilizó en la estimación de 1RM. La velocidad de ejecución fue de 4 segundos (2 en la fase excéntrica y 2 en la concéntrica) para realizar el movimiento completo, manteniendo un metrónomo a dicha velocidad. La serie donde los sujetos alcanzaban su 6RM era registrada para analizarla posteriormente. El tiempo de descanso entre series incrementaba de forma progresiva para determinar la 6RM en 3-5 intentos, de acuerdo al protocolo de la NSCA (Baechle & Earle, 2008).

En el test de 6RM de flexiones de brazos, la resistencia elástica fue incrementada progresivamente añadiendo el número de bandas requerido para realizar solo 6 repeticiones. Se utilizaron 70 cm de longitud del total de la banda para realizar el ejercicio. El investigador ayudaba a colocar la banda con dicha longitud por detrás de la espalda y a continuación, el sujeto extendía la banda para realizar el ejercicio con la amplitud de agarre adecuado (150% de distancia biacromial). Con el objetivo de iniciar un programa de entrenamiento de 5 semanas, al finalizar los test, los sujetos fueron divididos de forma aleatoria en 3 grupos: grupo de 6RM en press de banca, grupo de 6RM en flexiones de brazos con resistencia elástica y grupo control.

2.3.2.d Periodo de entrenamiento.

El programa de entrenamiento tuvo una frecuencia de 2 sesiones por semana (lunes y miércoles). Durante el periodo de entrenamiento se utilizaron los mismos ejercicios (realizados en el mismo lugar) y con las mismas variables (velocidad de ejecución, distancia de agarre y carga o resistencia) que durante la sesión de cálculo de 6RM. Cada sesión tenía una duración de unos 25 minutos y en ella se realizaban 5 series de 6 repeticiones. La misma carga y resistencia fueron mantenidas durante las 5 semanas. Se mantuvieron 4 minutos de descanso entre series durante el periodo de entrenamiento para mantener el número de repeticiones requerido sin disminuir la carga o resistencia (de Salles et al., 2009). Por otra parte, el grupo control fue instruido para mantener sus tareas habituales durante el trascurso del estudio.

2.3.3 Análisis de datos.

Las señales de EMG fueron analizadas utilizando el Matlab 7.0 (Mathworks Inc, Natick, MA, EEUU). Todas las señales fueron filtradas con un pasabandas de corte de frecuencia a 20-400Hz con un filtro Butterworth de cuarto orden. La amplitud de la señal de la EMG en el dominio del tiempo fue cuantificada utilizando RMS, procesada cada 100 milisegundos. Se determinaron los valores de la media y pico RMS para cada ejercicio y se normalizaron con el máximo de EMG de cada músculo (%MCVI). Así mismo, la media global de todos los músculos fue también calculada y analizada. Para normalizar las señales de EMG se utilizaron los 3 segundos medios de los 5 segundos de la MCVI. Durante los ejercicios dinámicos, el valor promedio de las 6 repeticiones realizadas en cada condición fue seleccionado para analizar la señal de EMG.

2.3.4 Análisis estadístico.

Para realizar el análisis estadístico se usó el software SPSS 19 para Windows (SPSS Inc., Chicago, IL, EEUU). Se comprobó que las variables mostraban una distribución normal (test de Shapiro-Wilk) antes de analizar los datos. Las comparaciones estadísticas de activación muscular entre condiciones se realizaron a través de una prueba t para muestras relacionadas. Los efectos del programa de entrenamiento se evaluaron con un ANOVA de medidas repetidas de dos factores (grupo y tiempo). Además, un ANOVA de un factor se realizó para evaluar las diferencias entre los porcentajes de cambio. En caso de detectarse un efecto principal significativo se utilizó un Post hoc con corrección de Bonferroni. El nivel de significancia se fijó a $p \leq 0.05$.

2.4 Artículo IV (Activación muscular durante el press de banca al focalizarse de forma selectiva en los músculos pectoral mayor o tríceps braquial).

2.4.1 Sujetos.

Un total de 18 hombres jóvenes participaron en el estudio. Los participantes tenían una experiencia de al menos un años en el entrenamiento de la fuerza, realizando 3 sesiones o más por semana a intensidades moderadas-altas. Ningún sujeto incluido en el estudio tenía la tensión arterial por encima de 160/100 ni padecía prolapso de disco o enfermedad crónica. Este estudio fue realizado en Copenhague, Dinamarca.

El número necesario de participantes fue calculado mediante el software PS - Power & Sample Size Calculation- (versión gratuita de Internet). Se necesitaban al menos 14 participantes. El cálculo se basó en un tamaño de efecto de 0.80 SD (es decir, un gran tamaño de efecto), con un nivel alpha de 0.05 y una potencia de 0.80.

2.4.2 Procedimientos experimentales.

Cada sujeto participó en 2 sesiones diferentes: una de familiarización y cálculo de 1RM y una sesión experimental con evaluación de EMG, realizadas con un mínimo 48 horas de separación entre ellas. Durante las mediciones, únicamente dos investigadores y un sujeto estuvieron presentes en la instalación al mismo tiempo, con el objetivo de no influir en la realización de los ejercicios.

2.4.2.a Sesión de cálculo de 1RM y familiarización.

En la primera sesión, en primer lugar se midió la altura (Seca model 217, Hamburg, Germany), el peso, el porcentaje graso (Tanita model MC-180MA, Tokio, Japón) y la distancia biacromial de cada sujeto. A continuación, los sujetos realizaron el calentamiento y se comenzó con la estimación de 1RM en el ejercicio de press de banca, siguiendo las pautas descritas por la NSCA (Baechle & Earle, 2008) y realizando el ejercicio con la misma técnica que se iba a utilizar en la sesión experimental. La determinación de la 1RM permitió calcular las cargas a utilizar durante la sesión experimental (20%, 40%, 50%, 60% y 80% de 1RM). Después de la prueba de 1RM, los sujetos se familiarizaron con las diferentes condiciones y con la misma técnica y pautas que se iban a utilizar durante la sesión de recolecta de datos. Para ello, los sujetos practicaron con una carga del 50% de 1RM al menos 3 veces en cada condición, hasta que el investigador y el participante quedaban satisfechos con la ejecución.

2.4.2.b Sesión experimental.

La segunda sesión comenzó con la preparación de la piel para la colocación de los electrodos. Para ello se rasuró con una cuchilla todo el vello que recubría los músculos de interés, se limpió la piel frotando con un algodón humedecido en un gel de lavado (Acqua gel, Meditec, Parma, Italia) para reducir la impedancia (Jakobsen et al., 2013). Posteriormente, se colocaron los electrodos en el lado dominante del cuerpo en los siguientes músculos: porción lateral, media y larga del tríceps braquial y porción clavicular y esternocostal del pectoral mayor, siguiendo recomendaciones establecidas (Criswell & Cram, 2011). Además, se colocaron electrodos a 2 cm del esternón en la porción clavicular y también a 2 cm del esternón en la porción esternocostal. Se emplearon electrodos autoadhesivos bipolares con gel (Blue Sensor M-00-S, Medicotest, Olstykke, Dinamarca) de 10 mm de diámetro en su parte activa. La distancia interelectrodos fue de 20 mm y el electrodo de referencia se situó a unos 10 cm del músculo, tal y como especifica el fabricante.

Una vez colocados los electrodos, los sujetos realizaron una flexión de brazos en el suelo para comprobar la señal de EMG. Todas las señales fueron adquiridas con una frecuencia de 1500Hz, amplificadas y convertidas de analógicas a digitales. Todos los registros de activación mioeléctrica (en microvoltios) fueron almacenados en un disco duro para su posterior análisis.

Los participantes empezaron cada condición partiendo desde una posición con los brazos extendidos, los antebrazos en pronación y los pies separados a la anchura biacromial. En la posición de flexión, los antebrazos se mantuvieron pronados, mientras que el codo fue flexionado hasta que la barra tocó el pecho y el hombro abducido aproximadamente a 45°. Cada participante utilizó una anchura de agarre estandarizada equivalente al 150% de la distancia biacromial. La cadera y la columna se mantuvieron en posición neutra. El ángulo de la articulación del codo fue medido constantemente con un inclinómetro electrónico (2D DTS inclination sensor, Noraxon, Arizona, EEUU), colocado en la parte lateral del húmero. El inclinómetro se sincronizó con los datos de EMG, utilizando un electromiógrafo de 16 canales (TeleMyo DTS Telemetry, Noraxon, Arizona, EEUU). Las fases concéntricas y excéntricas fueron definidas como los periodos con velocidad angular negativa o positiva respectivamente (de 90°-0° o 0°-90° respectivamente).

Los sujetos realizaron las siguientes condiciones en orden aleatorio: press de banca a 20%, 40%, 50%, 60% y 80% de 1RM. Además, los sujetos realizaron 3 condiciones diferentes con cada una de las intensidades mencionadas, asignadas de forma aleatoria: press de banca regular y press de banca focalizándose en usar selectivamente el pectoral mayor o el tríceps braquial. Las instrucciones para la focalización en el músculo pectoral mayor fueron las siguientes: "durante esta serie, intenta focalizarte en utilizar solo los músculos del pecho". Las instrucciones para la focalización en el músculo tríceps braquial fueron: "durante esta serie, intenta focalizarte en utilizar solo los músculos del tríceps". En el press de banca estándar, la instrucción fue: "durante esta serie, levanta el peso de forma normal". Un intervalo de descanso de 1 minuto entre series entre las diferentes condiciones fue dado, excepto después del 80% de 1RM, donde se concedieron 3 minutos de descanso para evitar mayor fatiga. Cada participante realizó 3 repeticiones consecutivas en cada condición para evitar la influencia de la fatiga en el siguiente ejercicio (Jakobsen et al., 2013). La velocidad de ejecución fue monitoreada con el software de EMG para seguir un ritmo de 2 segundos en la fase excéntrica y 2 segundos en la concéntrica. Durante las pruebas preliminares se encontró que el metrónomo era inviable para este propósito.

2.4.3 Análisis de datos.

Las señales de EMG durante los ejercicios fueron filtradas digitalmente, con un filtro de paso alto a 10 Hz y con un filtro RMS en movimiento con una anchura de 500 ms. Para cada músculo, se determinó el pico RMS de la señal de EMG en cada una de las 3 repeticiones realizadas en cada condición y la media de estas 3 repeticiones fue normalizada con el máximo RMS EMG obtenido durante la sesión para cada músculo ("maximal maximorum EMG"). Se calculó el promedio de los valores normalizados para las 4 diferentes porciones del pectoral mayor y las 3 diferentes porciones del tríceps braquial. Las señales del inclinómetro fueron filtradas con un pasabandas de corte de frecuencia a 3 Hz con un filtro Butterworth de cuarto orden.

2.4.4 Análisis estadístico.

Un análisis de medidas repetidas con un modelo lineal mixto de 2 factores (Proc Mixed, SAS version 9, SAS Institute, Cary, NC, EEUU) fue utilizado para determinar si había diferencias entre las condiciones y las diferentes intensidades. Cada músculo se analizó por separado. El nivel de significancia se fijó a $p \leq 0.05$.

RESULTADOS

3. Resultados y desarrollo argumental

3.1 Resultados.

A continuación, se muestra un resumen global de los principales resultados hallados en cada uno de los artículos que componen esta tesis.

3.1.1 Datos generales de la muestra.

Las características de los participantes de los artículos I-IV se exponen en la Tabla 1. En el Paper III (el único donde se llevó a cabo una intervención) no se observaron diferencias inter-grupo antes de comenzar con el desarrollo del programa de entrenamiento.

3.1.2 Artículo I (Activación muscular al realizar flexiones suspendidas con cuatro elementos de suspensión diferentes).

Se detectó una mayor activación muscular del tríceps braquial y el trapecio porción superior durante las flexiones de brazos realizadas con el dispositivo con polea (AirFit Trainer Pro) en comparación con el resto de condiciones. La activación de la porción anterior del deltoides fue mayor durante las flexiones de brazos estándar que durante el resto de condiciones excepto durante las flexiones suspendidas con el dispositivo de dos puntos de anclaje (Jungle Gym XT). Este dispositivo fue el que más activación generó en el pectoral mayor en comparación con el resto de condiciones. Respecto al recto anterior del abdomen, las flexiones de brazos realizadas con el dispositivo con polea (AirFit Trainer Pro) generaron más activación muscular que el resto de condiciones excepto al compararse con el Flying. En el erector lumbar espinal y el recto femoral, la activación fue mayor durante las flexiones suspendidas con el dispositivo con polea (AirFit Trainer Pro) en comparación con las otras condiciones. La Tabla 2 muestra los resultados completos.

Tabla 2. Media y error estándar (SE) de la activación de cada músculo y ejercicio expresados como porcentaje de la MCVI de cada músculo (n=29)

	Flexiones estándar (suelo)		TRX Suspension trainer		Jungle Gym XT		Flying		AirFit Trainer Pro		Sig (p)
	Media	SE	Media	SE	Media	SE	Media	SE	Media	SE	
Tríceps braquial	17.14[†,‡,§,||]	(1.31)	37.04[‡,||]	(1.80)	24.40[*,†,§,||]	(1.68)	34.93[*,‡,||]	(1.78)	47.82[*,†,‡,§]	(2.54)	<0.001
Trapecio porción superior	5.90[†,§,||]	(0.56)	15.73[*,‡,§,||]	(2.10)	6.35[†,§,||]	(0.77)	10.97[*,†,‡,||]	(1.54)	20.39[*,†,‡,§]	(2.65)	<0.001
Deltoides porción anterior	26.22[†,§,||]	(1.46)	19.08[*]	(0.91)	22.18[§]	(1.41)	17.70[*,‡]	(0.95)	18.46[*]	(1.24)	<0.001
Pectoral mayor porción clavicular	29.60[‡]	(1.88)	31.68[‡]	(2.53)	41.60[*,†,§,||]	(2.88)	30.59[‡]	(2.28)	27.69[‡]	(2.41)	<0.001
Recto anterior del abdomen	23.85[†,‡,§,||]	(2.80)	87.98[*,||]	(8.98)	87.13[*,||]	(9.27)	97.11[*]	(10.54)	105.53[*,†,‡]	(9.84)	<0.001
Recto femoral	7.45[†,‡,§,||]	(0.72)	11.86[*,||]	(1.28)	13.43[*,||]	(1.43)	12.36[*,||]	(1.21)	19.23[*,†,‡,§]	(2.20)	<0.001
Erector lumbar espinal	2.03[†,‡,§,||]	(0.14)	3.21[*,||]	(0.24)	3.26[*,||]	(0.23)	3.31[*,||]	(0.24)	4.32[*,†,‡,§]	(0.32)	<0.001
Global	16.75[†,‡,§,||]	(0.67)	30.50[*,||]	(1.75)	29.03[*,||]	(1.72)	30.62[*,||]	(1.91)	37.76[*,†,‡,§]	(2.27)	<0.001

MCVI: Máxima contracción voluntaria isométrica; n= tamaño muestral.
** =Diferencia respecto a las flexiones estándar en el suelo*
†= Diferencia respecto al TRX Suspension trainer
‡=Diferencia respecto al Jungle Gym XT
§ =Diferencia respecto al Flying
[||]=Diferencia respecto al AirFit Trainer Pro
Global = media de los 7 músculos

3.1.3 Artículo II (Activación muscular durante diferentes variaciones de flexiones de brazos y de press de banca y con polea en bipedestación, ambos realizados al 50%, 70% y 85% de 1RM).

Las cargas de la prueba de 1RM fueron menores ($p<0.001$) en el press con polea en bipedestación (13Kg) que en el press de banca (91.59Kg).

La activación del recto del abdomen fue mayor durante las flexiones suspendidas que durante el resto de condiciones. Lo mismo sucedió con la activación del oblicuo externo, excepto durante las flexiones suspendidas con el sistema en suspensión en “V” con ojos abiertos que no mostró diferencia respecto a las flexiones con resistencia elástica. La activación del pectoral mayor fue mayor durante el press de banca al 85% de 1RM que durante el resto de condiciones. El tríceps braquial se activó más durante las flexiones suspendidas con el dispositivo con polea que en el resto de condiciones. La activación de la porción anterior del deltoides fue mayor en el press de banca al 85% de 1RM que durante el resto de condiciones excepto en comparación con las flexiones con resistencia elástica. La porción superior del trapecio se activó más durante las flexiones suspendidas con el sistema en “V” y ojos abiertos que en el resto de condiciones excepto al compararse con las dos flexiones en el suelo, el resto de flexiones suspendidas, el press polea en bipedestación y el press de banca al 85% de 1RM. Respecto a la activación del serrato anterior, las dos variantes de flexiones en el suelo generaron mayor activación que el resto de condiciones excepto en comparación con el press de banca al 70% y al 85% de 1RM. El deltoides porción posterior se activó más durante las flexiones suspendidas con el dispositivo con polea. Los datos completos se muestran en la Tabla 3.

Tabla 3. Media y error estándar (SE) de la activación de cada músculo y ejercicio expresados como porcentaje de la MCVI de cada músculo (n=29)

Músculo	Flexiones estándar (A)	Flexiones resistencia elástica (B)	Flexiones suspendidas ojos cerrados (C)	Flexiones suspendidas ojos abiertos (D)	Flexiones suspendidas sistema polea (E)	Press banca 50%1RM (F)	Press banca 70%1RM (G)	Press banca 85%1RM (H)	Press polea de pie 50%1RM (I)	Press polea de pie 70%1RM (J)	Press polea de pie 85%1RM (K)
Recto anterior abdomen	13.31 (1.63)[c-k]	15.48 (1.72)[c-k]	57.08 (8.38)[a,b,f-k]	60.04 (10.20)[a,b,f-k]	65.82 (10.12)[a,b,f-k]	1.84 (0.30)[a-e,g,h]	3.33 (0.53)[a-f]	4.65 (0.62)[a-f,i]	2.00 (0.28)[a-e,h,k]	2.17 (0.21)[a-e]	3.34 (0.44)[a-e,i]
Oblicuo externo	25.14 (3.80)[c-g,i]	30.62 (4.06)[c,e,f-k]	56.02 (6.55)[a,b,f-k]	55.28 (7.43)[a,f-k]	74.61 (6.67)[a,b,f-k]	4.16 (0.73)[a-e,h]	5.18 (0.62)[a-e]	5.80 (0.66)[b-f]	4.55 (1.20)[b-e]	5.67 (1.22)[b-e]	6.05 (1.04)[b-e]
Pectoral mayor	23.58 (1.74)[b,g-k]	41.00 (2.46)[a,c-f,h-k]	30.57 (2.00)[b,e,h-k]	29.46 (1.70)[b,e,g-k]	22.80 (1.61)[b-d,g-k]	24.63 (2.25)[b,g-k]	40.48 (2.86)[a,d,e,f,h-k]	52.91 (3.28)[a-g,i-k]	4.11 (0.43)[a-h,k]	5.49 (0.52)[a-h]	7.03 (0.63)[a-j]
Deltoides porción anterior	29.68 (2.56)[b-e,h-k]	42.86 (2.96)[a,c-f,i-k]	17.79 (2.06)[a,b,g-j]	16.42 (1.41)[a,b,g-k]	14.45 (1.31)[a,b,g-i]	23.79 (2.26)[b,g-k]	33.91 (2.64)[c-f, h-k]	44.18 (2.69)[a,c-g,i-k]	8.44 (0.69)[a-h]	9.61 (0.93)[a-d,f-h]	9.87 (0.92)[a,b,d,f-h]
Tríceps braquial	13.99 (1.54)[b-e,h-k]	19.19 (1.72)[a,c-f,i-k]	30.54 (2.87)[a,b,e,f,g,i-k]	32.95 (3.41)[a,b,e,f,g,i-k]	41.14 (3.66)[a-d,f-k]	10.92 (1.07)[b,g-k]	16.53 (1.47)[c-f,h-k]	22.97 (2.13)[a,e,f,g,i-k]	1.07 (0.12)[a-h,k]	1.28 (0.13)[a-i]	1.39 (0.14)[a-j]
Trapecio porción superior	5.28 (0.65)[f]	7.77 (1.00)[f]	8.50 (1.22)[f]	9.40 (1.35)[f,g]	10.89 (2.07)	2.82 (0.31)[a-d,g,h]	4.05 (0.39)[d,f]	5.32 (0.64)[f]	4.26 (0.69)	4.76 (0.80)	4.30 (0.73)
Serrato anterior	24.38 (2.29)[c-f,i-k]	26.48 (1.92)[c-f,i-k]	13.68 (1.05)[a,b,e]	13.11 (1.32)[a,b,e,h]	9.83 (1.00)[a-d,h]	15.76 (2.01)[a,b,h]	21.82 (3.00)[i]	27.02 (3.45)[d,e,f,i-k]	9.26 (1.21)[a,b,g,h]	11.00 (1.39)[a,b,h]	11.24 (1.18)[a,b,h]
Deltoides porción posterior	2.50 (0.19)[b,e,f,h,j]	3.31 (0.23)[a,e,f,g,i-k]	4.11 (0.43)[e,f,i-k]	5.26 (0.69)[e,f,g,i-k]	9.95 (1.37)[a-d,f-k]	1.85 (0.15)[a-e,g-i]	2.47 (0.15)[b,d-f,h-k]	3.46 (0.24)[a,e,f,g,i-k]	0.90 (0.06)[a-h]	1.26 (0.15)[a-e,g,h]	1.26 (0.16)[b-e,g,h]
GLOBAL	18.82 (1.23)[b-f,i-k]	26.12 (1.41)[a,c-g,i-k]	31.10 (1.79)[a,b,f,g,i-k]	33.10 (2.14)[a,b,f,g,i-k]	36.23 (2.41)[a,b,f-k]	11.83 (0.67)[a-e,g-k]	18.00 (1.00)[b-f,h-k]	23.76 (1.29)[e,f,g,i-k]	5.13 (0.27)[a-h,j,k]	5.97 (0.37)[a-i]	6.70 (0.36)[a-i]
Ratio Serrato anterior / trapecio superior	3.04 (0.32)[d,e]	2.42 (0.24)[e]	1.41 (0.18)[h]	1.25 (0.20)[a,f,h]	0.78 (0.11)[a,b,f-h]	5.80 (1.03)[d,e]	5.33 (0.96)[e]	4.80 (0.66)[c-e]	1.78 (0.33)	2.26 (0 .54)	1.92 (0.36)

MCVI: Máxima contracción voluntaria isométrica; n= tamaño muestral.
[a] Diferencias respecto a flexiones estándar; [b] Diferencias respecto a flexiones con Resistencia elástica; [c] Diferencias respecto a flexiones suspendidas con ojos cerrados; [d] Diferencias respecto a flexiones suspendidas con ojos abiertos; [e] Diferencias respecto a flexiones suspendidas con el sistema con polea; [f] Diferencias respecto al press de banca 50%1RM; [g] Diferencias respecto al press de banca 70%1RM; [h] Diferencias respecto al press de banca 85%1RM; [i] Diferencias respecto al press polea en bipedestación 50%1RM; [j] Diferencias respecto al press polea en bipedestación 70%1RM; [k] Diferencias respecto al press polea en bipedestación 85%1RM.

3.1.4 Artículo III (Respuestas agudas en la activación muscular durante 6RM de press de banca y 6RM de flexiones de brazos con resistencia elástica y respuestas crónicas en las ganancias de fuerza tras utilizar un ejercicio u otro con dicha intensidad).

Los valores de EMG en el pectoral mayor (media: p= 0.927; pico: p= 0.968) y la porción anterior del deltoides (media: p= 0.244; pico: p= 0.934) mostraron una ausencia de diferencias entre las 6RM de flexiones de brazos con resistencia elástica y 6RM de press de banca. Los resultados de EMG se muestran en la Tabla 4.

Respecto a los resultados de la intervención, los sujetos que entrenaron a 6RM en el press de banca y los que entrenaron 6RM de flexiones de brazos con resistencia elástica obtuvieron similares mejoras en los test de 6RM y 1RM en el press de banca, mientras que el grupo control no mejoró. Estos resultados se exponen en las tablas 5 y 6.

Tabla 4. Valores de activación media y pico entre condiciones (n=30). Los datos se expresan como valor medio (SE) en %MCVI.

	Media %MCVI		Pico %MCVI	
	Pectoral mayor	Deltoides anterior	Pectoral mayor	Deltoides anterior
Resistencia elástica	52.90 (2.55)	62.32 (2.87)	139.73 (6.87)	139.69 (6.10)
Press de banca	52.70 (1.85)	59.53 (3.54)	139.98 (6.66)	139.28 (7.70)

MCVI: Máxima contracción voluntaria isométrica; n= tamaño muestral.
SE: error estándar de la media

Tabla 5. 6RM en press de banca (kg) antes y después de la intervención.

Los datos se expresan como media (SD).

	Pre-test	Post-test	Δ (%)	p	p interacción
Control	52.51 (20.49)	53.59 (19.87)	2.72 (0.08)	0.344	
Flexiones	53.20 (13.59)	62.57 (11.51) †	21.04* (0.22)	<0.001	0.007
Press banca	57.70 (18.45)	69.95 (21.07) †	22.21* (0.13)	<0.001	

* Diferente respecto a grupo control; † Diferente respecto a pre-test.
RM: Repetición máxima
SD: desviación estándar

Tabla 6. 1RM en press de banca (kg) antes y después de la intervención. Los datos se expresan como media (SD).

	Pre-test	Post-test	Δ (%)	p	p interacción
Control	64.45 (26.82)	65.57 (27.48)	1.68 (0.02)	0.497	
Flexiones	66.75 (13.71)	75.33 (13.98) †	13.65* (0.14)	<0.001	< 0.001
Press banca	70.64 (20.05)	83.70 (23.57) †	19.84* (0.20)	<0.001	

* Diferente respecto a grupo control; † Diferente respecto a pre-test.
RM: Repetición máxima
SD: desviación estándar

3.1.5 Artículo IV (Activación muscular durante el press de banca al focalizarse de forma selectiva en los músculos pectoral mayor o tríceps braquial).

Los valores normalizados de EMG fueron acordes a las cargas relativas. Por ejemplo, el press de banca regular al 50% de 1RM tuvo unos valores de EMG en el pectoral mayor y tríceps braquial de 52% y 55% respectivamente. En ambos músculos, focalizarse en utilizar un músculo en concreto incrementó la activación en ese músculo en cargas de entre el 20% y 60% de 1RM. Parece existir un umbral entre el 60% y 80% de 1RM para poder incrementar la activación de forma selectiva. Focalizarse en utilizar el tríceps braquial no redujo la actividad del pectoral mayor, sino que incluso la aumentó durante el 50% y 60% de 1RM. A continuación se muestran los resultados completos de EMG durante las diferentes condiciones (Tabla 7).

Tabla 7. EMG normalizada (intervalo de confianza 95%) del pectoral mayor y el tríceps braquial durante el press de banca regular y el press de banca con focalización en utilizar uno u otro músculo. Las diferencias entre las condiciones y los valores de p se proporcionan en las últimas columnas.

	% 1 RM	Press banca Regular	Focalización pectoral mayor	Focalización tríceps braquial	Δ Focalización pectoral mayor - Regular	P	Δ Focalización tríceps braquial - Regular	P
Pectoral mayor EMG	20	21 (16 - 25)	28 (23 - 32)	20 (15 - 24)	7 (3 - 10)	<.0001	-1 (-4 - 3)	0.6288
	40	38 (34 - 43)	44 (39 - 48)	40 (35 - 44)	5 (2 - 9)	0.0037	1 (-2 - 5)	0.3973
	50	52 (47 - 56)	57 (53 - 62)	55 (51 - 60)	6 (2 - 9)	0.0018	4 (0 - 7)	0.0383
	60	56 (52 - 61)	65 (61 - 70)	61 (57 - 66)	9 (5 - 12)	<.0001	5 (1 - 8)	0.0072
	80	81 (77 - 86)	80 (75 - 84)	82 (77 - 87)	-1 (-5 - 2)	0.4888	1 (-3 - 4)	0.6082
Tríceps braquial EMG	20	31 (26 - 36)	32 (27 - 36)	42 (37 - 47)	1 (-3 - 4)	0.6141	11 (8 - 15)	<.0001
	40	47 (42 - 52)	46 (41 - 50)	53 (48 - 58)	-1 (-5 - 2)	0.499	6 (3 - 10)	0.0004
	50	55 (50 - 60)	54 (49 - 59)	59 (54 - 64)	-1 (-4 - 3)	0.6002	4 (0 - 7)	0.0296
	60	60 (55 - 65)	59 (54 - 64)	64 (60 - 69)	-1 (-4 - 3)	0.7365	5 (1 - 8)	0.0082
	80	80 (75 - 85)	81 (76 - 85)	82 (78 - 87)	1 (-3 - 4)	0.7031	3 (-1 - 6)	0.1408

RM: Repetición máxima

Discusión

3.2 Discusión.

En el presente apartado se muestra un resumen global de la discusión razonada de los resultados obtenidos.

En primera instancia, cabe destacar que los principales hallazgos de esta tesis son 1) el dispositivo de suspensión con polea (AirFit Trainer Pro) generó mayor activación que el resto de dispositivos en todos los músculos excepto en el pectoral mayor y la porción anterior del deltoides, 2) en general, las flexiones suspendidas generaron la mayor activación abdominal entre los diferentes ejercicios de empuje, las flexiones de brazos con resistencia elástica generaron similar activación en el pectoral mayor que el press de banca al 70% de 1RM, el press de banca generó mayor activación en los principales movilizadores que el press polea en bipedestación, 3) el press de banca y las flexiones de brazos realizados a 6RM generaron comparables valores de EMG y de ganancias de fuerza, 4) los sujetos fueron capaces de incrementar la activación del tríceps braquial o el pectoral mayor cuando se focalizaban en uno u otro músculo a intensidades comprendidas entre el 20% y el 60% de 1RM, pero no al 80% de 1RM.

A continuación se realiza un resumen global de la discusión de cada uno de estos hallazgos.

3.2.1 Artículo I (Activación muscular al realizar flexiones suspendidas con cuatro elementos de suspensión diferentes).

El objetivo del Artículo I fue comparar la activación muscular al realizar flexiones suspendidas con cuatro dispositivos de suspensión de diferentes características. De acuerdo con la hipótesis, el dispositivo con polea (AirFit Trainer Pro) generó la mayor activación en todos los músculos excepto en el pectoral mayor y la porción anterior del deltoides. Sin embargo, contrariamente a lo pensado, hubo diferencias en la activación muscular del pectoral mayor entre condiciones estables e inestables.

Se detectó mayor activación muscular del tríceps braquial durante las flexiones de brazos realizadas con el dispositivo con polea (AirFit Trainer Pro) en comparación con el resto de condiciones. La gran mayoría de estudios (los cuales utilizan flexiones con el propio peso) reportan mayor activación muscular del tríceps braquial durante las flexiones de brazos suspendidas que durante la versión tradicional (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014; Snarr & Esco, 2013), así como también reportan más activación durante flexiones de brazos realizadas sobre otros materiales específicos que generan inestabilidad (Anderson et al., 2013; Lehman et al., 2006) en comparación con las versiones estables. Por contra, Freeman et al. (2006) encontraron la misma activación muscular durante la realización de flexiones de brazos con las dos manos en dos balones que con la versión estable del ejercicio. No obstante, podría ser que la cantidad de inestabilidad provocada por los balones no fuera suficiente como para encontrar diferencias significativas. Parece lógico además, que durante condiciones de inestabilidad se produzca una mayor dificultad para realizar las flexiones de brazos con la técnica correcta, especialmente a la hora de realizar una adecuada flexo-extensión de la articulación del codo, acción en la que el tríceps braquial desempeña un papel esencial (Kendall & Kendall, 2005).

Al igual que el músculo tríceps braquial, la porción superior del trapecio se activó más durante las flexiones de brazos realizadas con el dispositivo con polea en comparación con el resto de condiciones. Probablemente esto se deba a los mayores desequilibrios unilaterales permitidos por este dispositivo y la correspondiente necesidad del trapecio de estabilizar la escápula (Lear & Gross, 1998). De acuerdo a esta idea, una flexión de brazos unilateral y mantenida en un balón mostró mayor activación en este músculo que el mismo ejercicio sobre superficie estable (de Oliveira et al., 2008). En línea con los resultados de esta tesis, otros estudios realizados en nuestra unidad de investigación han corroborado la mayor activación de la porción superior del trapecio durante las flexiones suspendidas con dispositivos de un anclaje en comparación con la versión estable del ejercicio (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014). Del mismo modo, media flexión de brazos suspendida provocó mayor actividad en el trapecio superior que la versión estable del ejercicio (De Mey et al., 2014), por lo que nuestros resultados parecen coherentes.

Diferentes patrones de activación muscular tuvieron la porción anterior del deltoides y el pectoral mayor. La activación de la porción anterior del deltoides fue mayor durante las flexiones de brazos estándar que durante el resto de condiciones, excepto en comparación con el dispositivo de dos puntos de anclaje (Jungle Gym XT). Este mismo dispositivo de dos anclajes fue el que además generó mayor activación muscular en el pectoral mayor en comparación con las otras condiciones. Estos resultados sugieren que una condición de ejercitación más estable puede promover mayor o igual cantidad de activación en estos músculos que otras condiciones de entrenamiento más inestables. De forma opuesta, Snarr & Esco (2013) encontraron mayor activación del pectoral mayor y porción anterior del deltoides durante la versión suspendida de flexiones de brazos. Sin embargo, los resultados de tres estudios realizados en nuestra unidad de investigación van en la línea de la presente tesis, siendo las flexiones tradicionales las que generaban mayor (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014) o similar (Borreani, Calatayud, Colado, Moya-Nájera, et al., 2015) activación en la porción anterior del deltoides y además produciendo la misma activación muscular en el pectoral mayor (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014) en comparación con la versión suspendida. De forma parecida, un estudio previo encontró que las flexiones de brazos en el suelo generaban el mismo valor numérico de EMG en la porción anterior del deltoides que las flexiones sobre dos balones (Freeman et al., 2006). Este mismo estudio encontró además valores numéricos mayores (20%MCVI) en el pectoral mayor durante la versión inestable de los ejercicios anteriormente comentados (Freeman et al., 2006), a pesar de que no se conoce la diferencia estadística de estos resultados. Otro estudio previo no mostró diferencias en la actividad muscular del pectoral mayor al realizar flexiones de brazos sobre un “Swiss ball” o flexiones de brazos en condición estable (Lehman et al., 2006). Los autores de este estudio afirman que la ausencia de cambios en la activación del pectoral mayor se debe a que su rol durante este ejercicio es sobre todo movilizador y no estabilizador. Otros autores sugieren que es necesario ejercitarse en condiciones de inestabilidad moderada y no excesiva para incrementar la activación de este y otros músculos (Behm & Colado, 2012; Behm et al., 2010).

Respecto al erector lumbar espinal y el recto femoral, la activación muscular fue mayor durante las flexiones suspendidas realizadas con el dispositivo con polea (AirFit Trainer Pro) en comparación con las otras condiciones. Además, todas las flexiones en condición de suspensión activaron más ambos músculos que las flexiones estándar. Similarmente, dos estudios de nuestro grupo de investigación reportan que el erector lumbar espinal (Calatayud et al., 2014) y el recto femoral (Borreani, Calatayud, Colado, Moya-Nájera, et al., 2015) se activaron más en la versión suspendida de flexiones de brazos, probablemente debido a la mayor necesidad de estabilización en varias articulaciones. No obstante, los niveles de activación encontrados en la presente tesis en el erector lumbar espinal y el recto femoral pueden ser considerados como bajos (Digiovine, Jobe, Pink, & Perry, 1992). En línea con estos hallazgos, estudios previos encontraron baja activación muscular durante flexiones de brazos en condiciones inestables (Anderson et al., 2013; Beach et al., 2008; Calatayud et al., 2014; Freeman et al., 2006) y durante ejercicios con posiciones similares como el "press-up" (Marshall & Murphy, 2005) o el puente prono (Lehman, Hoda, & Oliver, 2005). Puesto que una activación excesiva en la musculatura lumbar se ha relacionado con altas fuerzas compresivas y de cizallamientos (Juker et al., 1998), nuestros hallazgos sugieren que las flexiones suspendidas generan una cantidad de activación segura para la columna vertebral (Escamilla et al., 2010). Niveles de activación bajos en la musculatura lumbar pueden ser apropiados debido a su alta proporción de fibras tipo I (Behm & Colado, 2012) y al rol predominante que tiene la resistencia muscular durante las actividades diarias (McGill, 2001). Se ha sugerido que una activación alta del recto femoral causa mayor lordosis lumbar (Sundstrup, Jakobsen, Andersen, Jay, & Andersen, 2012), incrementando el riesgo de dolor en esta zona (Youdas et al., 2008). Sin embargo, debido a que no se conocen los niveles de activación relacionados con una mayor lordosis lumbar, algunas personas deben tener cuidado al realizar flexiones de brazos con dispositivos de suspensión puesto que estos incrementan el riesgo de lesión lumbar en comparación con la versión tradicional (Beach et al., 2008; McGill et al., 2014).

De manera semejante a lo ocurrido con los músculos citados anteriormente, el dispositivo con la polea provocó mayor activación muscular que todas las condiciones, con excepción del dispositivo de entrenamiento en suspensión denominado "Flying". Cabe destacar también que los mayores niveles de actividad muscular del estudio se encontraron en el recto anterior del abdomen. Independientemente del dispositivo de suspensión utilizado, la activación en este músculo alcanzó valores muy altos (87%-106%MCVI), siendo mayor que durante las flexiones estándar. Varios estudios previos han mostrado resultados similares, donde las flexiones suspendidas incrementaron la activación del recto anterior del abdomen en comparación con la versión tradicional (Beach et al., 2008; Calatayud et al., 2014). Del mismo modo, McGill et al. (2014) encontraron valores numéricos en la activación de este músculo que fueron más del doble durante la versión suspendida de las flexiones, aunque no se proporcionaron datos sobre diferencias estadísticas.

De manera análoga, otras condiciones de ejercitación en inestabilidad han demostrado inducir una mayor cantidad de activación en el recto anterior del abdomen que las condiciones estables durante la realización de flexiones de brazos (Anderson et al., 2013; Freeman et al., 2006), durante variaciones de flexiones tradicionales como son por ejemplo el "press up on top" (Marshall & Murphy, 2005) o los "push-ups plus" (Lehman et al., 2006) e incluso durante diferentes ejercicios que implican posiciones semejantes como el puente prono realizado tanto en suspensión (Snarr & Esco, 2014) como sobre un "Swiss ball" (Lehman et al., 2005).

3.2.2 Artículo II (Activación muscular durante diferentes variaciones de flexiones de brazos y de press de banca y con polea en bipedestación, ambos realizados al 50%, 70% y 85% de 1RM).

Si bien en el Artículo I se pudieron comprobar las diferencias en la activación que proporcionaba el uso de diferentes dispositivos de suspensión, era necesario establecer comparaciones entre diferentes alternativas para realizar ejercicios de empuje, como por ejemplo la utilización de resistencia elástica y el uso de métodos más tradicionales, donde el empleo de pesos facilita el incremento de la intensidad. Por tanto, el Artículo II pretendió evaluar la activación muscular durante diferentes variaciones de flexiones de brazos y comparar su activación con la del press de banca y el press polea en bipedestación, ambos realizados al 50%, 70% y 85% de 1RM.

Confirmando la primera hipótesis del Artículo II, los niveles de activación más elevados fueron encontrados en la musculatura abdominal (recto anterior del abdomen y oblicuo externo) y fueron generados por los dispositivos de suspensión. Estos resultados concuerdan con lo encontrado en el Artículo I y en otros estudios previos donde las flexiones suspendidas generaron mayor activación del recto anterior del abdomen que la versión tradicional (Beach et al., 2008; Calatayud et al., 2014; McGill et al., 2014). Aunque no se reportaron diferencias entre las diferentes flexiones suspendidas, parece que mayores desequilibrios unilaterales y cerrar los ojos son variaciones que aumentan la activación muscular en comparación a las flexiones con resistencia elástica. Al contrario que un estudio previo (Santana et al., 2007), nuestros resultados mostraron que la activación de la musculatura abdominal fue similar en los dos ejercicios de press. No obstante, la realización del press en bipedestación en nuestro estudio fue bilateral en lugar de unilateral, pudiendo ser la causa de esta diferencia de resultados (Saeterbakken & Fimland, 2012).

De acuerdo con nuestra segunda hipótesis, las flexiones de brazos con resistencia elástica demostraron similar activación en el pectoral mayor que el press de banca a 70% de 1RM. Además, esta variante con resistencia elástica generó mayor activación en este músculo que las otras variantes de flexiones. De manera interesante, las flexiones suspendidas en el dispositivo con polea generaron menor activación muscular en el pectoral mayor que el resto de flexiones realizadas en suspensión. La explicación a esto podría ser el excesivo desequilibrio postural que se produce durante esta variante y la dificultad para producir fuerza de forma adecuada. Las flexiones suspendidas con ojos cerrados fueron las únicas de las realizadas en suspensión que obtuvieron activación similar del pectoral mayor a la del press de banca a 70% de 1RM. Tal y como se encontró en el Artículo I y en otros estudios de nuestra unidad de investigación (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014), las condiciones estables o moderadamente inestables generan mayor activación en este músculo que aquellas que proporcionan mayor inestabilidad. Por tanto, no es de extrañar pues, que la activación muscular del pectoral mayor durante el press de banca al 85% de 1RM fuera mayor que en el resto de condiciones evaluadas. De esta manera, la tercera hipótesis del Artículo II queda confirmada ya que el press de banca generó mayor activación en los principales movilizadores que el press polea en bipedestación, algo que ya fue encontrado en un estudio anterior (Santana et al., 2007).

También es importante señalar que se encontró una clara disminución de las cargas durante la prueba de 1RM en el press polea en bipedestación en comparación con la 1RM del press de banca, coincidiendo con resultados previamente reportados (Santana et al., 2007). A pesar de esto, la mayor activación del tríceps braquial se encontró en las flexiones suspendidas realizadas con el dispositivo con polea, en analogía con lo encontrado en el Artículo I. Cuando las flexiones de brazos se realizan en condiciones de inestabilidad, la activación muscular del tríceps braquial se ve incrementada. Por el contrario, durante ejercicios más estables (como el press de banca o las flexiones con resistencia elástica) parece ser que la clave para aumentar la activación de este músculo es la utilización de mayores cargas y la mayor producción de fuerza, tal y como sucedió con el press de banca en nuestro estudio, o incluso con el press polea en bipedestación. Resultados previos concuerdan con esta afirmación, ya que por ejemplo, se encontró que durante la realización de 6RM en press de banca sobre una superficie inestable se veían reducidas tanto las cargas levantadas como la activación del tríceps braquial (Saeterbakken & Fimland, 2013).

En otro orden de cosas, los resultados encontrados en la EMG de la porción anterior del deltoides sugieren que situaciones de ejercitación con alta inestabilidad comprometen las adaptaciones positivas en este músculo. Por ejemplo, las flexiones realizadas en el suelo mostraron mayor activación muscular en la porción anterior del deltoides que las suspendidas, resultados acordes con lo encontrado en el Artículo I. Además, estudios recientes de nuestro laboratorio corroboran que las flexiones tradicionales generaban mayor (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014) o similar (Borreani, Calatayud, Colado, Moya-Nájera, et al., 2015) activación en la porción anterior del deltoides que la versión suspendida. De hecho, la resistencia elástica añadida a las flexiones de brazos en el suelo generó una activación comparable en este músculo a la generada por el press de banca al 70% y 85% de 1RM.

Al contrario, el deltoides porción posterior se activó más en general durante las flexiones suspendidas (especialmente con el dispositivo con polea), probablemente debido a la mayor co-contracción antagonista durante las condiciones de mayor inestabilidad (Behm et al., 2010). En concordancia con resultados previos durante flexiones de brazos tradicionales, este músculo mostró los niveles de activación más bajos (Youdas et al., 2010).

Respecto al músculo serrato anterior, de acuerdo con resultados previos (McGill et al., 2014), se encontró mayor activación durante la versión estable de las flexiones de brazos que durante la variante realizada en suspensión. Similarmente, se encontró mayor activación del serrato anterior durante el press de banca que durante el press polea en bipedestación cuando ambos se realizaban al 85% de 1RM. La porción superior del trapecio mostró diferentes patrones de activación muscular, siendo las flexiones suspendidas con el sistema en "V" y ojos abiertos la única condición que mostró mayor activación que el press de banca a 70% de 1RM. Estos resultados van en la línea de lo encontrado en el Artículo I y en diversos estudios (Borreani, Calatayud, Colado, Tella, et al., 2015; Calatayud et al., 2014; McGill et al., 2014), donde las flexiones suspendidas activaron más el trapecio porción superior que la versión estable. Ejercicios que minimizan la activación de la porción superior del trapecio mientras maximizan la activación del serrato anterior se han recomendado en sujetos con desequilibrios escapulares (Ludewig, Hoff, Osowski, Meschke, & Rundquist, 2004). Nuestros resultados sugieren que los ratios de activación serrato anterior/trapecio superior más favorables se dan durante las flexiones en el suelo o el press de banca.

Se ha asumido que los ejercicios deben alcanzar niveles de activación muscular del 40% al 60% de la MCVI para producir adaptaciones de fuerza (Andersen et al., 2006). Nuestros resultados en el press de banca a 50% de 1RM indican que menores niveles de activación (24.63%MCVI) podrían ser efectivos. Sin embargo, es difícil establecer un umbral de activación mínimo ya que esta variable se ve afectada por diferentes factores como la experiencia de entrenamiento (Wahl & Behm, 2008), la técnica de normalización (Criswell & Cram, 2011) o el tipo de análisis de la señal que se aplica. Por tanto, una forma más adecuada de asociar una determinada activación muscular con adaptaciones de fuerza sería mediante la comparación entre ejercicios que se realizan a un %RM o número de RM, tal y como se hizo en este estudio.

3.2.3 Artículo III (Respuestas agudas en la activación muscular durante 6RM de press de banca y 6RM de flexiones de brazos con resistencia elástica y respuestas crónicas en las ganancias de fuerza tras utilizar un ejercicio u otro con dicha intensidad).

La hipótesis de partida de esta investigación fue que el ejercicio de flexiones de brazos con bandas elásticas podría alcanzar la misma activación que el press de banca si se utiliza la misma intensidad relativa (6RM) y que además, se generarían similares ganancias de fuerza muscular al entrenar con uno u otro ejercicio. Los resultados de este estudio mostraron que ambos ejercicios generaron valores comparables de EMG y de ganancias de fuerza después de un programa de entrenamiento de 5 semanas, corroborándose así la hipótesis inicial.

Concretamente, las 6RM en flexiones de brazos y las 6RM en el press de banca generaron la misma activación en el pectoral mayor y la porción anterior del deltoides. En línea con esto, estudios previos encontraron que la resistencia elástica y los pesos libres inducían la misma activación en la musculatura del cuello, hombros, antebrazo (Andersen et al., 2010) y en el bíceps braquial (Aboodarda et al., 2013). Además, diversos estudios han encontrado que la resistencia elástica alcanzaba niveles similares de EMG a los pesos libres o máquinas al realizar ejercicios para la extremidad inferior como las zancadas o “lunge” (Jakobsen et al., 2013), la extensión de rodilla (Jakobsen et al., 2012) y la flexión de rodilla (Jakobsen et al., 2014).

A lo largo de los años se ha asumido que aquellos ejercicios que producen una señal similar de EMG generarán ganancias de fuerza similares (Andersen et al., 2006, 2010; Blackard et al., 1999). Sin embargo, ningún estudio había verificado esto a través de una intervención de entrenamiento aplicando ejercicios que previamente han demostrado valores similares de activación, tal y como se hizo en este estudio. Además, tal y como se había dicho en el Artículo II, activaciones por debajo del umbral de 60% de la MCVI se consideraban inefectivas (Andersen et al., 2006), afirmación que se basaba en las recomendaciones del ACSM (2009).

Tanto en este estudio como en el Artículo II se encontraron activaciones del 53% de la MCVI en el pectoral mayor durante ejercicios de alta intensidad, que además en el caso del Artículo III, fue adecuada para generar ganancias de fuerza muscular tras el periodo de entrenamiento. Estudios de intervención previos demostraron que la resistencia elástica producía similares ganancias de fuerza en mujeres jóvenes y sanas que los pesos libres y máquinas (Colado et al., 2010) y que las máquinas en mujeres sedentarias de mediana edad (Colado & Triplett, 2008). Sin embargo, ningún estudio había evaluado los efectos agudos y crónicos del uso de resistencia elástica durante las flexiones de brazos. Nuestros resultados muestran que este método de entrenamiento mejora las pruebas de 6RM y 1RM en el press de banca de forma comparable al entrenamiento tradicional con el press de banca, cuando los ejercicios se realizan a la misma intensidad, volumen, descanso, técnica y velocidad de movimiento. A pesar de que podría pensarse que el entrenamiento en el press de banca tendría una mayor transferencia en los test (Rutherford & Jones, 1986), puesto que eran el mismo ejercicio, parece ser que las similitudes biomecánicas entre los dos ejercicios (Blackard et al., 1999) evitaron que esto así sucediera.

Contrariamente a nuestros resultados, un estudio previo no reportó cambios en la prueba de 1RM en el press de banca tras un programa de entrenamiento con flexiones (Chulvi-Medrano, Martínez-Ballester, & Masiá-Tortosa, 2012). Sin embargo, en este estudio se realizaron flexiones sin resistencia añadida y por tanto, es muy probable que la intensidad fuera insuficiente como para promover ganancias de fuerza, algo que sí sucedió en nuestra investigación.

Si en el Artículo II se descubrió que la resistencia elástica añadida a las flexiones de brazos era una prometedora alternativa a los ejercicios tradicionales para conseguir adaptaciones de fuerza, el Artículo III termina de corroborar esta idea, posicionando a este ejercicio como una alternativa real al clásico press de banca. La utilización de bandas elásticas es una forma práctica de aplicar resistencia añadida en cualquier parte, como por ejemplo una clínica de rehabilitación o unas instalaciones deportivas tanto interiores como exteriores.

3.2.4 Artículo IV (Activación muscular durante el press de banca al focalizarse de forma selectiva en los músculos pectoral mayor o tríceps braquial).

En los Artículos I-III, se analizó el efecto de diferentes ejercicios de empuje, estableciendo comparaciones entre medios o métodos tradicionales y alternativos de entrenamiento basados en la utilización de distintos materiales. Por el contrario, en el Artículo IV se pretendió evaluar la posibilidad de activar selectivamente el pectoral mayor o el tríceps braquial al focalizarse en uno u otro músculo durante el press de banca, en comparación con la realización tradicional del ejercicio.

El principal hallazgo fue que los sujetos fueron capaces de incrementar la activación muscular del tríceps braquial o del pectoral mayor cuando se focalizaban en uno u otro músculo a intensidades comprendidas entre el 20% y el 60% de 1RM, pero no así al 80% de 1RM. En contraste con la hipótesis formulada inicialmente, la habilidad para incrementar la activación muscular de forma selectiva no disminuyó con la intensidad, sino que hubo un umbral entre el 60% y el 80% de 1RM donde la activación selectiva dejó de ser posible. De hecho, solo el tríceps braquial se pudo activar más de forma selectiva durante el 20% que durante las otras intensidades. Para el resto de intensidades por debajo del 80% de 1RM los incrementos de activación en los dos músculos estuvieron entre el 5% y el 9%.

Los resultados de este estudio van en analogía con lo encontrado por Snyder and Fry (2012), que mostraron que futbolistas con una experiencia de al menos 6 meses con el ejercicio eran capaces de activar de forma selectiva los músculos pectoral mayor y tríceps braquial durante el press de banca al 50% de 1RM. Sin embargo, al contrario que en nuestros resultados, la instrucción para activar el pectoral mayor durante el 80% de 1RM generó mayor activación en este músculo y la porción anterior del deltoides, sin mostrar cambios en el tríceps braquial.

Parece ser que el esfuerzo requerido en los principales movilizadores durante el 80% de 1RM hace que la activación selectiva sea más complicada, seguramente debido a la mayor necesidad de reclutar más unidades motoras y la mayor producción de fuerza. A pesar de que la activación fue incrementando junto con el incremento de las intensidades, es poco probable que la realización de 3 repeticiones no máximas causara un umbral de reclutamiento máximo y por tanto imposibilitara aumentos de la activación al 80% de 1RM. Es más probable que los sujetos no pudieran disociar entre una activación selectiva y la propia activación requerida para levantar el peso, tal y como se ha dicho antes. De hecho, gran parte de los estudios que encuentran aumentos de la activación después de instrucciones específicas en movimientos dinámicos utilizaron intensidades más bajas que en nuestro estudio, como el propio peso corporal como carga (Critchley, 2002; Karst & Willett, 2004) o cargas de entre 30% y 50% de la máxima intensidad (Bressel et al., 2009; Snyder & Leech, 2009).

De manera interesante, se encontró un incremento de activación concurrente en el pectoral mayor cuando los sujetos se focalizaban en activar el tríceps braquial durante intensidades de 50% y 60% de 1RM, algo que no sucedió al contrario. No se han reportado reducciones de la activación concurrente durante el press de banca (Snyder & Fry, 2012), si bien es cierto que algunos autores han demostrado la posibilidad de reducir voluntariamente la activación, aunque eso sí, a bajas intensidades y en otros músculos y ejercicios, tanto dinámicos (Karst & Willett, 2004) como isométricos (Palmerud et al., 1998).

La razón principal de nuestros hallazgos podría ser la "hipótesis de acción restringida" (Wulf, Shea, & Park, 2001), que explica las diferencias entre adoptar una focalización externa (donde la atención se fija en el efecto de la acción o medida) y la focalización interna (donde la atención se fija en la acción o el movimiento). De acuerdo con esta teoría, una focalización externa generará menor activación muscular que la interna, debido a la mayor coherencia entre el input sensorial y la respuesta motora (McNevin & Wulf, 2002), reclutando la mínima cantidad necesaria de unidades motoras (Vance, Wulf, Töllner, McNevin, & Mercer, 2004). Ya que las instrucciones proporcionadas en nuestro estudio suponen la adopción de una focalización interna, nuestros resultados van en la línea de lo encontrado en diferentes estudios. Por ejemplo, diversos autores encontraron que durante una flexión de codo, el adoptar una focalización externa reducía la activación en el bíceps braquial en comparación con la focalización interna (Greig & Marchant, 2014; Marchant, Greig, & Scott, 2009; Vance et al., 2004).

3.3 Fortalezas y limitaciones.

La presente tesis se ha desarrollado siguiendo todo el rigor y el conocimiento científico posible. Sin embargo, llegados a este punto de la exposición argumental, se hace necesario señalar sus fortalezas y limitaciones para poder concluirla de la manera más coherente posible.

Es conocido que la señal de EMG puede tener interferencias o registros de señales de otros músculos cercanos a los que se está evaluando, algo conocido como “cross-talk” (Criswell & Cram, 2011). Sin embargo, esto puede ser minimizado mediante el uso de una distancia inter-electrodos adecuada (Hermens et al., 2000). Además, todos los procedimientos de medición de EMG se realizaron basándose en recomendaciones establecidas, las cuales han sido utilizadas en numerosos estudios realizados en nuestra unidad de investigación.

Tal y como se menciona en el Artículo II, es difícil establecer un umbral de activación mínimo y establecer comparaciones entre estudios, ya que el valor de esta variable se ve afectado por diferentes factores. No obstante, la comparación entre medios y métodos entrenamiento alternativos con otros tradicionales realizados a un %RM o número de RM, tal y como se hizo en los Artículos II y III supone una fortaleza de la presente tesis.

Por otra parte, en el Artículo IV, la medición de la musculatura antagonista podría haber proporcionado información interesante. A pesar de ello, en el Artículo IV, la utilización de un valor medio para las diferentes porciones de un mismo músculo supone una fortaleza, proporcionando un valor de EMG más representativo, lo que en este estudio es particularmente relevante.

Los estudios que componen esta tesis se realizaron con sujetos que tenían experiencia de entrenamiento y por tanto, los resultados podrían no extrapolarse a otras poblaciones o diferentes músculos y ejercicios. Sin embargo, las características de la muestra empleada representa de manera adecuada el tipo de población que más suele practicar esta clase de ejercicios y entrenamientos.

3.4 Futuras investigaciones.

Tras la experiencia atesorada a lo largo de la presente tesis, se puede indicar que son necesarios nuevos estudios para evaluar la activación muscular y la efectividad de ejercicios para el entrenamiento de la fuerza realizados con medios y métodos alternativos, como así son los que generan inestabilidad durante la realización de diversos movimientos o los que aportan una resistencia de tipo elástico.

Además, la utilización de la técnica de activación muscular selectiva durante la realización de ejercicios para el entrenamiento de la fuerza necesita mayor investigación, especialmente en ejercicios dinámicos y que impliquen la utilización de un gran número de grupos musculares y articulaciones. También sería interesante, por ejemplo, conocer los posibles efectos de este método para incrementar la actividad muscular en ejercicios ampliamente utilizados en el ámbito de la rehabilitación y en situaciones donde existe una incapacidad para utilizar altas intensidades, resistencias externas o incluso existe una restricción del movimiento.

Finalmente debe también remarcarse que son necesarios futuros estudios para comprobar los efectos a largo plazo de los diferentes medios y métodos investigados en la presente tesis.

Conclusiones

4. Conclusiones

La presente tesis demuestra que existen cantidad de alternativas a los métodos convencionales para alcanzar niveles altos de actividad muscular (y por tanto ganancias de fuerza) durante la utilización de ejercicios de empuje. Los resultados aportados pueden ser utilizados para atender a los principios de variación y progresión del entrenamiento, proporcionando un elevado grado de flexibilidad para el diseño de programas de entrenamiento de la fuerza.

A continuación, se describirán sucintamente las principales conclusiones de la presente tesis, en concordancia con los objetivos planteados en cada unos de los artículos que la componen.

Artículo I

Cuando se realiza entrenamiento en suspensión con el peso corporal, el dispositivo con polea es la mejor opción para incrementar la activación del tríceps braquial, el trapecio superior, el recto femoral y el erector lumbar espinal. Por el contrario, el pectoral mayor y la porción anterior del deltoides requieren de condiciones más estables. Así, el dispositivo con dos anclajes es la mejor opción para el pectoral mayor. Sin embargo, las flexiones suspendidas no suponen una ventaja para activar la porción anterior del deltoides en comparación con la versión estándar del ejercicio. Todos los dispositivos de suspensión activan de manera efectiva el recto anterior del abdomen.

Artículo II

Las flexiones realizadas con resistencia elástica generan similar activación en los principales movilizadores que el press de banca realizado a alta intensidad, provocando al mismo tiempo mayor activación en la musculatura abdominal. Sin embargo, la mejor opción para estimular la musculatura abdominal son las flexiones suspendidas. La activación del pectoral mayor, porción anterior del deltoides y serrato anterior es mayor durante condiciones más estables, mientras que los músculos del abdomen, el tríceps braquial y el deltoides porción posterior se activan más en situaciones de mayor inestabilidad.

Artículo III

6RM en press de banca y 6RM en flexiones de brazos con resistencia elástica generan valores comparables de EMG y ganancias de fuerza muscular. Así, cuando los niveles de activación muscular son comparables y los ejercicios de empuje sean biomecánica y cinemáticamente similares, las ganancias de fuerza serán similares.

Artículo IV

La activación del tríceps braquial o el pectoral mayor incrementa al focalizarse en uno u otro músculo durante el press de banca realizado hasta intensidades del 60% de 1RM. Parece existir un umbral entre 60% y 80% de 1RM.

4. Conclusions (English)

The present PhD project shows several alternatives to conventional methods for reaching high levels of muscle activity (and thus muscle strength gains) during upper-body push exercises. The results provided may be used to attend the variation and progression principles of training, providing a large degree of flexibility in designing resistance training programs.

The main conclusions of the present doctoral thesis will be briefly described below, in concordance with the aims established for each different paper.

Paper I

When suspension training with the own body weight is performed, the pulley system is the best option to increase triceps brachii, upper trapezius, rectus femoris and erector lumbar spinae muscle activity. On the contrary, more stable conditions are needed for the pectoralis major and the anterior deltoid. Thus, the two-anchor system is the best option to increase pectoralis major activity. However, the suspended push-ups did not provide an additional advantage to increase anterior deltoid activity compared with the standard version of the exercise. All the suspension systems effectively increase rectus abdominis activity.

Paper II

Elastic-resisted push-ups induce similar muscle activity in the prime movers as the bench press performed at high load while also provides a greater abdominal activity. However, suspended push-ups were the best option to stimulate abdominal muscles. Muscle activity of the pectoralis major, anterior deltoid and anterior serratus is higher during more stable pushing conditions, whereas abdominal muscles, triceps brachii, posterior deltoid and upper trapezius were more active during the unstable exercises.

Paper III

The 6RM bench press and the 6RM elastic-resisted push-ups provide both comparable EMG values and muscle strength gains. Thus, when the levels of muscle activity are comparable and the kinematics and biomechanics of the push exercises are broadly similar, the gain in muscle strength will be similar.

Paper IV

The triceps brachii or pectoralis major muscle activity increase during the bench press when focusing on using either of these specific muscles at intensities up to 60% of 1RM. A threshold between 60% and 80% appeared to exist.

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ANEXOS

Categorización de las publicaciones de la presente tesis doctoral

Artículo	Revista	Factor de impacto*	Área temática	Ranking	Cuartil
1	Journal of Sports Science and Medicine	1.025	Sport sciences	57/81	3
2	The Physician and Sports medicine	1.085	Sport sciences	54/81	3
3	Journal of Strength and Conditioning Research	2.075	Sport sciences	23/81	2
4	European Journal of Applied Physiology	2.187	Sport sciences	21/81	2

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Publicaciones científicas relacionadas con la presente tesis

Borreani, S., **Calatayud, J.**, Colado, J. C., Tella, V., Moya-Nájera, D., Martin, F., & Rogers, M. E. (2015). Shoulder muscle activation during stable and suspended push-ups at different heights in healthy subjects. *Physical Therapy in Sport, 16*(3), 248–254. http://doi.org/10.1016/j.ptsp.2014.12.004

Calatayud, J., Borreani, S., Colado, J. C., Martín, F. F., Rogers, M. E., Behm, D. G., & Andersen, L. L. (2014). Muscle Activation during Push-Ups with Different Suspension Training Systems. *Journal of Sports Science & Medicine, 13*(3), 502–510.

Calatayud, J., Borreani, S., Colado, J. C., Martin, F., & Rogers, M. E. (2014). Muscle activity levels in upper-body push exercises with different loads and stability conditions. *The Physician and Sportsmedicine, 42*(4), 106–119. http://doi.org/10.3810/psm.2014.11.2097

Calatayud, J., Borreani, S., Colado, J. C., Martin, F., Tella, V., & Andersen, L. L. (2015). Bench press and push-up at comparable levels of muscle activity results in similar strength gains. *Journal of Strength and Conditioning Research, 29*(1), 246–253. http://doi.org/10.1519/JSC.0000000000000589

Calatayud, J., Vinstrup, J., Jakobsen, M. D., Sundstrup, E., Brandt, M., Jay, K., … Andersen, L. L. (2015). Importance of mind-muscle connection during progressive resistance training. *European Journal of Applied Physiology*, *116*(3), 527–533. http://doi.org/10.1007/s00421-015-3305-7

Difusión de la presente tesis en eventos científicos internacionales

Haines, T.L., Martín, F., Borreani, S., **Calatayud, J**., Moya, D., & Colado, J.C. (2013). Muscular activation during push-ups performed on suspension training devices with different types of anchoring. NSCA 36th Annual National Conference, Las Vegas, Nevada (EEUU).

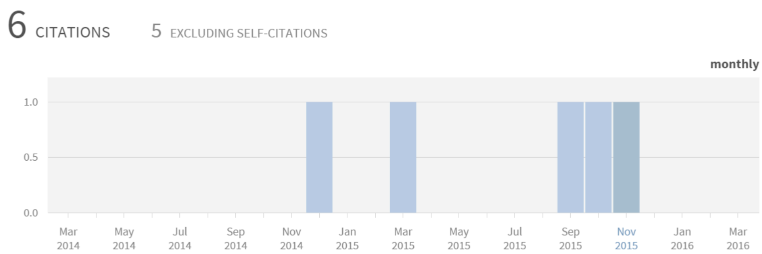
Capps, C., **Calatayud, J**., Borreani, S., Colado, J.C., Moya, D., & Martín, F. (2013). Comparison of muscle recruitment during bench press exercise with elastic bands vs. a fixed-bar trajectory. NSCA 36th Annual National Conference, Las Vegas, Nevada (EEUU).

Rogers, N.L., **Calatayud, J**., Borreani, S., Colado, J.C., Tripplet, N.T., Andersen, L.L., & Rogers, M.E. (2014). Serratus Anterior and Upper Trapezius Muscle Activity During Upper-Body Exercises. ACSM 61th Annual Meeting y 5th World Congress on Exercise is Medicine, Orlando, Florida (EEUU).

Calatayud, J., Borreani, S., Colado, J.C., Martin, F., Behm, D.G., & Rogers, M.E. (2014). Neuromuscular comparison of push-up variations and bench press. ACSM 61th Annual Meeting y 5th World Congress on Exercise is Medicine, Orlando, Florida (EEUU).

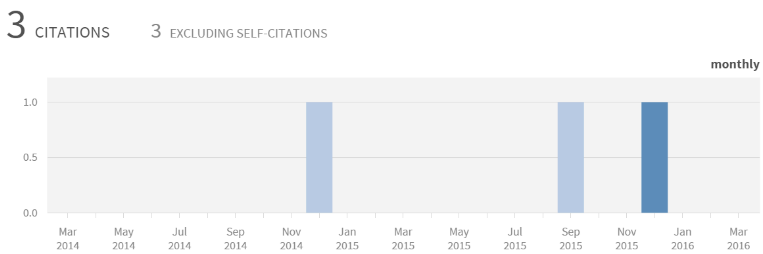
Citaciones de las publicaciones de la presente tesis en revistas científicas internacionales*

Artículo I



*FUENTE:https://www.researchgate.net/publication/265214725_Muscle_Activation_during_Push-Ups_with_Different_Suspension_Training_Systems?ev=prf_pub

Artículo II



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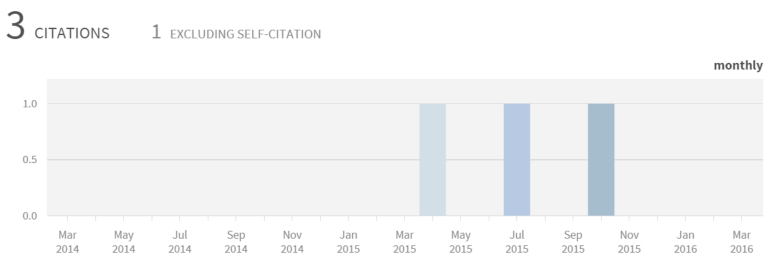
Artículo III



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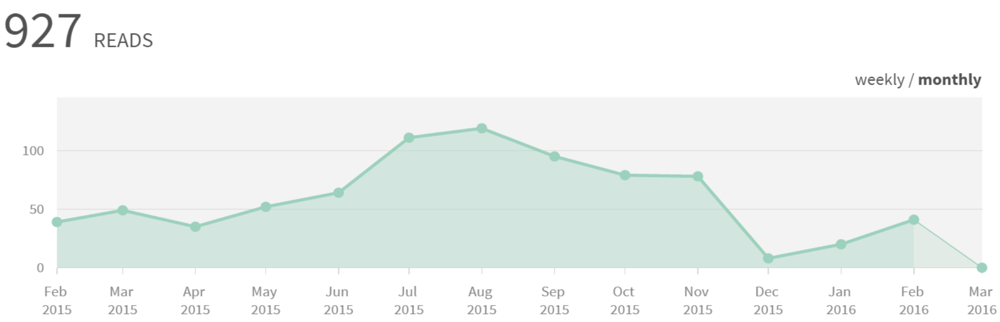

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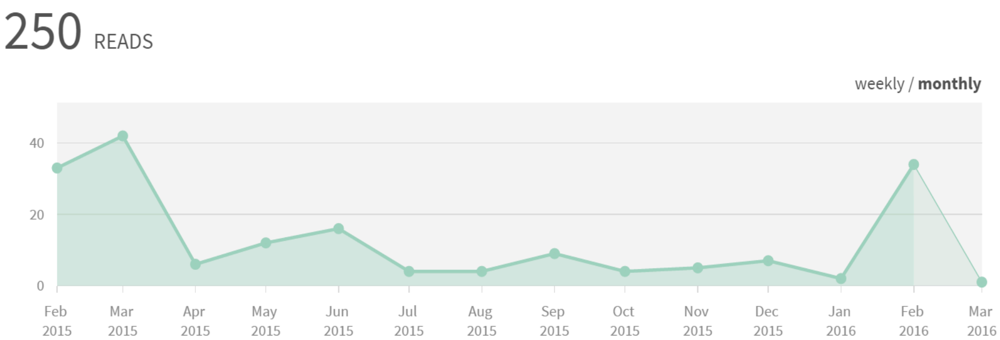

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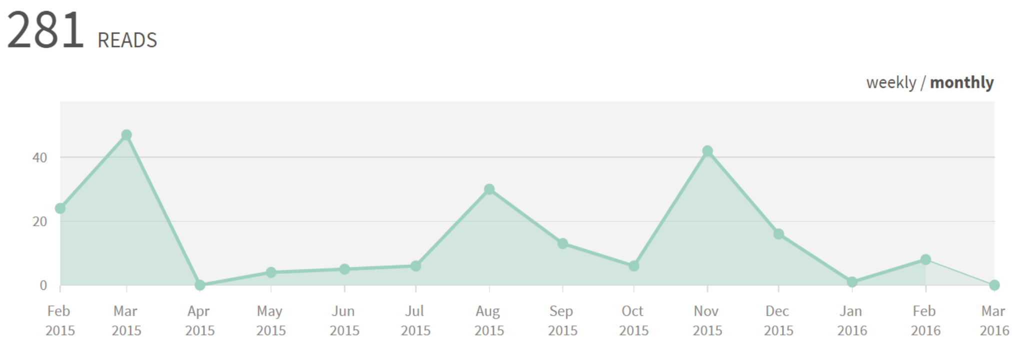

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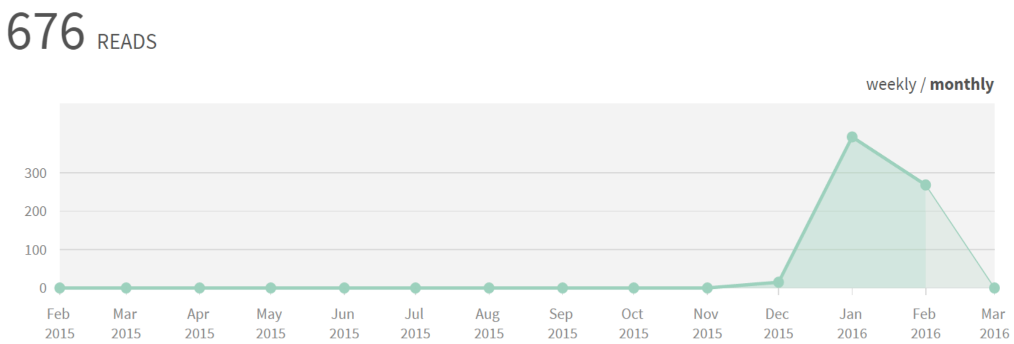
Artículo IV



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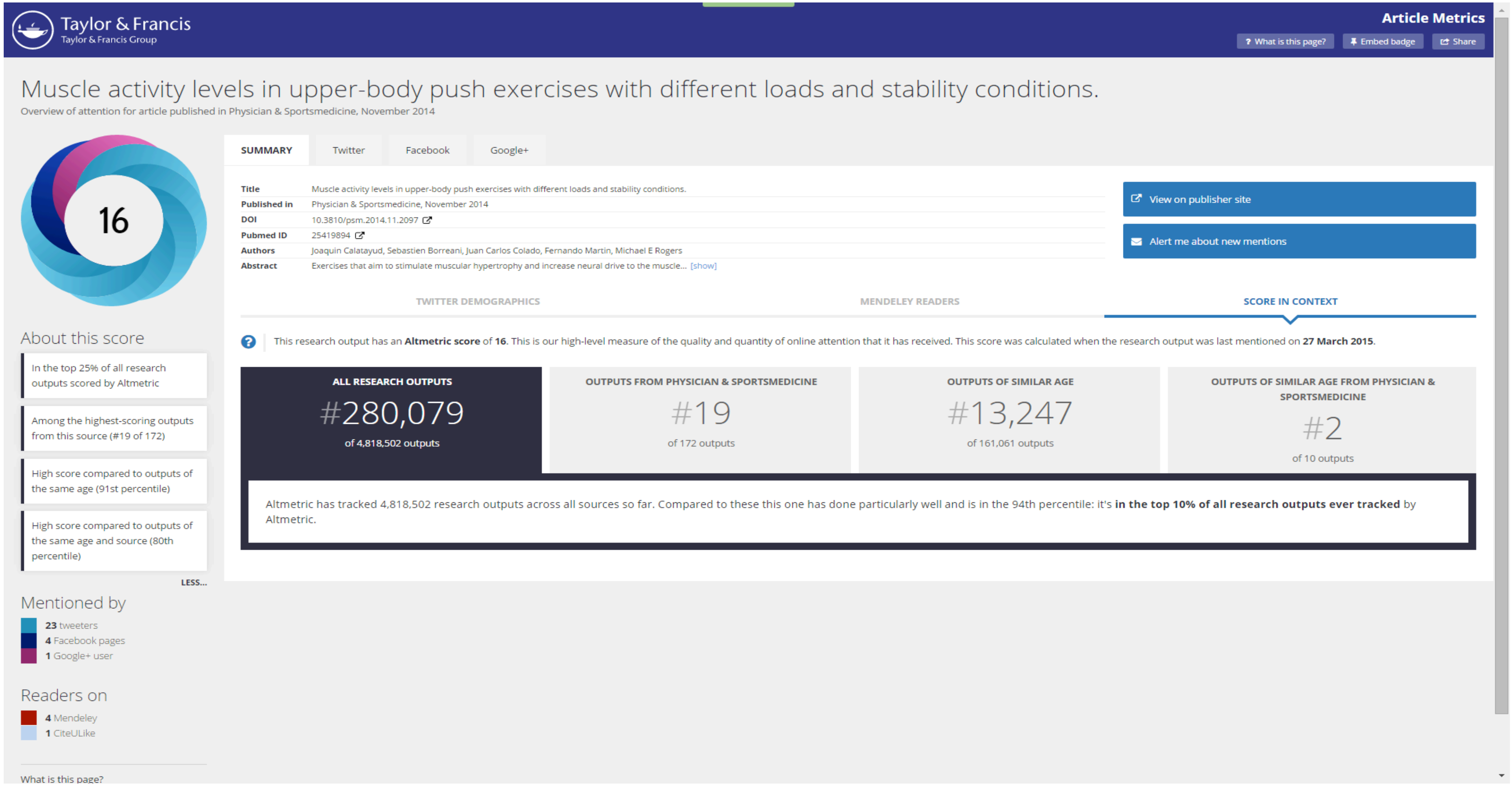

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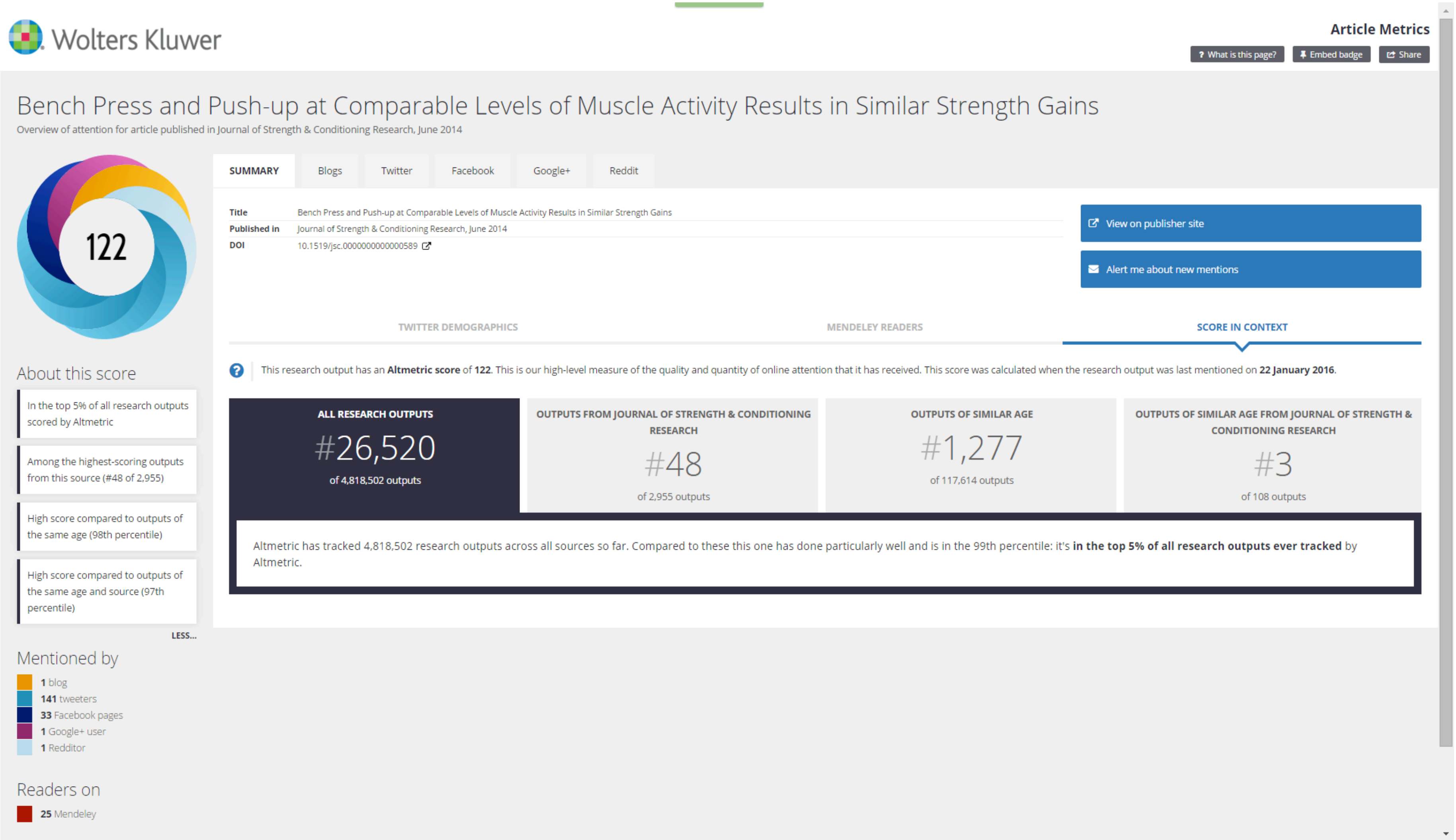

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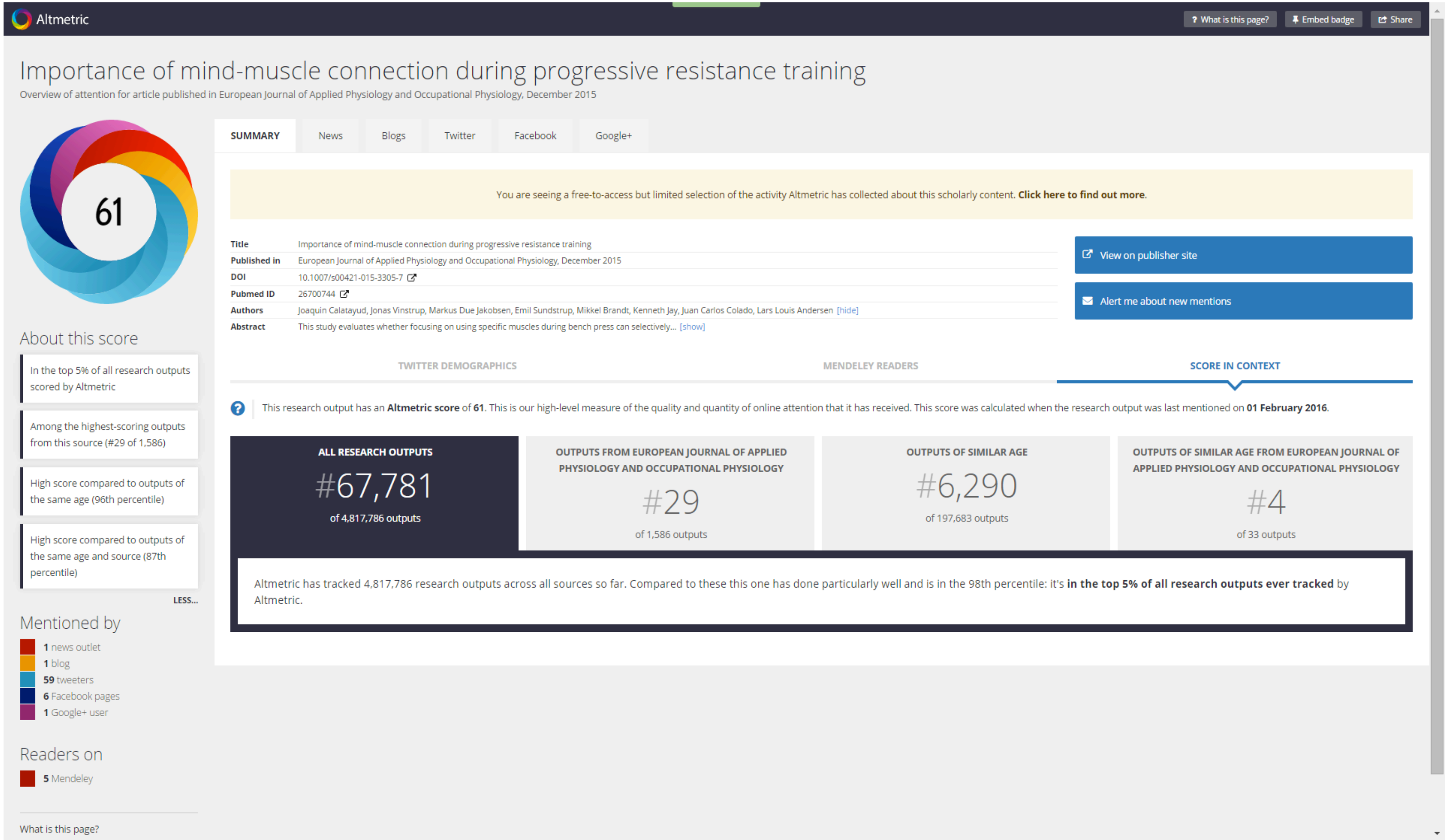
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Research article

Muscle Activation during Push-Ups with Different Suspension Training Systems

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Abstract

The purpose of this study was to analyze upper extremity and core muscle activation when performing push-ups with different suspension devices. Young fit male university students (n = 29) performed 3 push-ups each with 4 different suspension systems. Push-up speed was controlled using a metronome and testing order was randomized. Average amplitude of the electromyographic root mean square of Triceps Brachii, Upper Trapezius, Anterior Deltoid, Clavicular Pectoralis, Rectus Abdominis, Rectus Femoris, and Lumbar Erector Spinae was recorded. Electromyographic signals were normalized to the maximum voluntary isometric contraction (MVIC). Electromyographic data were analyzed with repeated-measures analysis of variance with a Bonferroni post hoc. Based upon global arithmetic mean of all muscles analyzed, the suspended push-up with a pulley system provided the greatest activity (37.76% of MVIC; $p < 0.001$). Individually, the suspended push-up with a pulley system also provided the greatest triceps brachii, upper trapezius, rectus femoris and erector lumbar spinae muscle activation. In contrast, more stable conditions seem more appropriate for pectoralis major and anterior deltoid muscles. Independent of the type of design, all suspension systems were especially effective training tools for reaching high levels of rectus abdominis activation.

Key words: EMG, unstable, core, trunk, exercise.

Introduction

The use of unstable devices is a popular option in the fitness world (Behm and Colado, 2012). This training modality is recommended for individuals aiming to achieve functional resistance training and health benefits (Behm et al., 2010). It is well established that use of unstable devices can increase core activation (Behm et al., 2010). Since decreased core muscle strength is associated with low back pain, there is a large emphasis on strengthening the trunk muscles (McGill, 2001). Instability resistance training can also increase limb muscle activation (Anderson and Behm, 2005) and co-contractions (Behm et al., 2002). In addition, a recent review found that instability resistance training programs achieved on average 22% gains in functional performance measures (Behm and Colado, 2012).

Whereas many unstable devices (e.g., Swiss balls, BOSU balls, rocker boards) provide an unstable base, suspension training can provide alternative instability to upper and lower limbs and the core. Although suspension training is portrayed as an innovative training technique, the historical use of these devices is related to the classic gymnastics rings (Beach et al., 2008).

One of the functional exercises that can be performed with suspension devices is the push-up which is a traditional exercise that has been used to train trunk, arm and shoulder musculature (Youdas et al., 2010). The push-up is also recommended in upper extremity rehabilitation programs for advanced training of the scapular stabilizers (Lear and Gross, 1998).

While muscle activation comparing push-ups using stable and unstable platforms or surfaces has been investigated (Behm et al., 2002, Freeman et al., 2006; Lehman et al., 2006), there are only two articles (Beach et al., 2008; McGill et al., 2014) using suspension training systems. Beach et al. (2008) reported greater activation of the abdominal muscles with suspended push-ups in comparison with standard push-ups. Nevertheless, while this study compared a single suspension system with parallel bands to a stable position, no previous studies have compared different types of suspension systems with different anchors and characteristics which may possess varying degrees of stability and muscle activation. Further, no data are available in regard to the muscle activity differences for the primary muscles involved in the suspended push-up exercise. It is also important to know whether differences in muscle activation with these devices are different between core/trunk and limbs.

Despite the wide variety of suspension training systems that are available and the increasing use of these devices, there is a lack of scientific evidence about the muscle activity that may be induced by the different system characteristics, hindering an optimal training tool selection. Thus, the purpose of this study was to compare the muscle activation while performing a push-up with four different conditions/suspension training systems such as V configuration systems (i.e., V-Shaped) with one anchor (i.e., TRX Suspension Trainer and Flying), one-anchor V-Shaped system with a pulley (i.e., AirFit Trainer Pro) and a parallel band system with two independent anchors (i.e., Jungle Gym XT). It was hypothesized that the highest core and upper extremities muscle activation would be induced by the suspension system with the pulley, except for the pectoralis major and anterior deltoid, which were expected to show similar muscle activation in stable and unstable conditions.

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Methods

Subjects

Young fit male university students (n = 29; age: 23.5 ± 3.1 years; height: 1.78 ± 0.06 m; body mass: 75.2 ± 8.5 kg; body fat percentage: 10.0 ± 2.5 % and biacromial (shoulder) width: 39.1 ± 1.5cm) voluntarily participated in this study. The number of participants chosen was calculated and based on effect size 0.25 SD with an α level of 0.05 and power at 0.80. Participants had a minimum of 1 year of resistance training experience, performing at least 2 sessions per week and a minimum of 4 months of suspension training experience, using this kind of training at least 1 time per week. No participant included in this study had musculoskeletal pain, neuromuscular disorders, or any form of joint or bone disease. All participants signed an institutional informed consent form before starting the protocol, and the institution's review board approved the study. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

Experiment procedures

Each participant took part in 2 sessions: familiarization and experimental sessions both at the same hour during the morning. The first session occurred 48-72 h before the data collection in the experimental session. Several restrictions were imposed on the volunteers: no food, drinks or stimulants (e.g., caffeine) to be consumed 3-4 h before the sessions and no physical activity more intense than daily activities 12 h before the exercises. They were instructed to sleep more than 8 hours the night before data collection. All measurements were made by the same investigators during the morning and the procedures were always conducted in the same sportive facility (with temperature at 20º C). The study was conducted during April.

Familiarization session

During the familiarization session, the participants were familiarized with the push-up exercise, suspension training equipment, movement amplitude, body position and cadence of movement that would later be used during data collection. Participants practiced the exercises typically 1-3 times each until the participant felt confident and the researcher was satisfied that the form had been achieved. Moreover, height (IP0955, Invicta Plastics Limited, Leicester, England), body mass, body fat percentages (Tanita model BF- 350) and biacromial width were obtained according to the protocols used in previous studies (García-Massó et al., 2011).

Experimental session

The protocol started with the preparation of participants' skin, followed by electrode placement, MVIC collection and exercise performance. Hair was removed with a razor from the skin overlying the muscles of interest, and the skin was then cleaned by rubbing with cotton wool dipped in alcohol for the subsequent electrode placement (positioned according to the recommendations of Cram et al., 1998) on the Triceps Brachii (TRICEP), Upper Trapezius (TRAPS), Anterior Deltoid (DELT), Clavicular Pectoralis (PEC), Rectus Abdominis (ABS), Rectus Femoris (FEM), and Lumbar Erector Spinae (LUMB) on the dominant side of the body. Pre-gelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S, Medicotest, Olstykke, DNK) were placed with an interelectrode distance of 25 mm. The reference electrode was placed between the active electrodes, approximately 10 cm away from each muscle, according to the manufacturer's specifications. Once the electrodes were placed, participants performed 2 standard push-ups on the floor in order to check signal saturation. All signals were acquired at a sampling frequency of 1kHz, amplified and converted from analog to digital. All records of myoelectrical activity (in microvolts) were stored on a hard drive for later analysis. To acquire the surface EMG signals produced during exercise, an ME6000P8 (Mega Electronics, Ltd., Kuopio, Finland) biosignal conditioner was used.

Prior to the dynamic exercises described below, two 5 s MVICs were performed for each muscle and the trial with the highest EMG was selected (Jakobsen et al., 2013). Participants performed 1 practice trial to ensure that they understood the task, 1-minute rest was given between each MVIC and standardized verbal encouragement was provided to motivate all participants to achieve maximal muscle activation. Positions for the MVICs were performed according to standardized procedures, chosen based on commonly used muscle testing positions for the (1) TRICEP (Kendall et al., 2005) , (2) PEC (Snyder and Fry, 2012), (3) DELT (Ekstrom et al., 2005), (4) TRAPS (Ekstrom et al., 2005), (5) ABS (Vera-García et al., 2010), (6) LUMB (Jakobsen et al., 2013), (7) FEM (Jakobsen et al., 2013) and were performed against a fixed immovable resistance (i.e., Smith machine). Specifically: (1) forearm extension with elbows at 90º in a seated position an erect posture with no back support (2) bench press with a grip at 150% of biacromial width, the shoulder abducted at 45º and feet flat on the bench (3) deltoid flexion at 90º in a seated position with an erect posture with no back support (4) deltoid abduction at 90º in a seated position with an erect posture with no back support (5) curl up at 40º with arms on chest and pressing against the bar with the participant lying on the bench and feet flat on the bench, (6) trunk extension with the participant lying on the bench and pelvis fixated, the trunk was extended against the bar, and (7) static knee extension with the participant positioned in a Biodex dynamometer: knee angle: 70º and hip angle: 110º.

The participants started the push-ups in an extended arm (up) position with forearms and wrists pronated, feet at biacromial (shoulder) width, and fingers flexed. In the down position, the forearm and wrists were kept pronated, whereas the elbow was flexed 90º and the shoulder abducted 45º. A cross line auto laser level was fixated with a tripod (Black & Decker LZR6TP, New Britain, CT, USA) and used as a visual feedback for researchers in connection to requested elbow and shoulder joint positioning during exercises. Hip and spine were maintained neutral and hands grasping the handles at 10 cm from the floor during all the repetitions. Each participant performed three consecutive repetitions in all conditions to avoid the influence of fatigue on the subsequent condition (Jakobsen et al., 2013). A 2:2 ratio (i.e., 2-second rate for descent and 2-second rate for ascent) was maintained by a 30-Hz metronome (Ableton Live 6, Ableton AG, Berlin, Germany) to standardize speed of movement (Freeman et al., 2006). Each participant used a standardized grip width of 150% of biacromial width (distance in centimeters between the tips of right and left third digits). Visual feedback was given to the participants in order to maintain the range of movement and hand distance during the data collection. A trial was discarded and repeated if participants were unable to perform the exercise with the correct technique.

Exercise equipment

The suspended push-ups were performed with 4 different suspension training systems: TRX Suspension Trainer ™ (TRX®, San Francisco, CA, USA), Jungle Gym XT (LifelineUSA®, Madison, WI, USA), Flying (Sidea, Cesea, Italy), AirFit Trainer Pro (PurMotion™, Pelham, AL, USA). The main characteristic of the suspension equipment is that two bands or cables are suspended from the ceiling or other support. Each device has unique characteristics (see Figure 1). TRX Suspension Trainer ™ is quite common in fitness centers. This equipment has a main band and on the bottom of this band there is a main carabineer and a stabilizing loop where another band is locked, forming a V with handles on the bottom. Flying equipment is very similar to the TRX Suspension Trainer, except that there are two V bands instead of one band with a stabilizing loop in the middle. AirFit Trainer Pro has a main band supported by a spring and a V cable with a pulley in the middle. Therefore, friction is reduced and it allows greater unilateral motion. Greater unilateral movements provide disruptive torques that contribute to instability (Behm and Colado, 2012) and thus this equipment is considered the most unstable. Finally, Jungle Gym XT provides a more stable condition than the other suspension devices due to a neutral suspension system with two parallel bands (similar to Olympic rings) and two independent anchors, in contrast to traditional V-shaped suspension systems.The band length for all devices was adjusted for the hands to be at 10 cm from the floor during all repetitions. The order of conditions was performed randomly with a 2-min interval rest time between them.

Data analysis

All surface EMG signal analyses were performed using Matlab 7.0 (Mathworks Inc., Natick, MA, USA). Surface EMG signals related to isometric exercises were analyzed by using the 3 middle seconds of the 5-second isometric contraction. The EMG signals of the dynamic exercises were analyzed by taking the average of the entire three repetitions. All signals were bandpass filtered at a 20- to

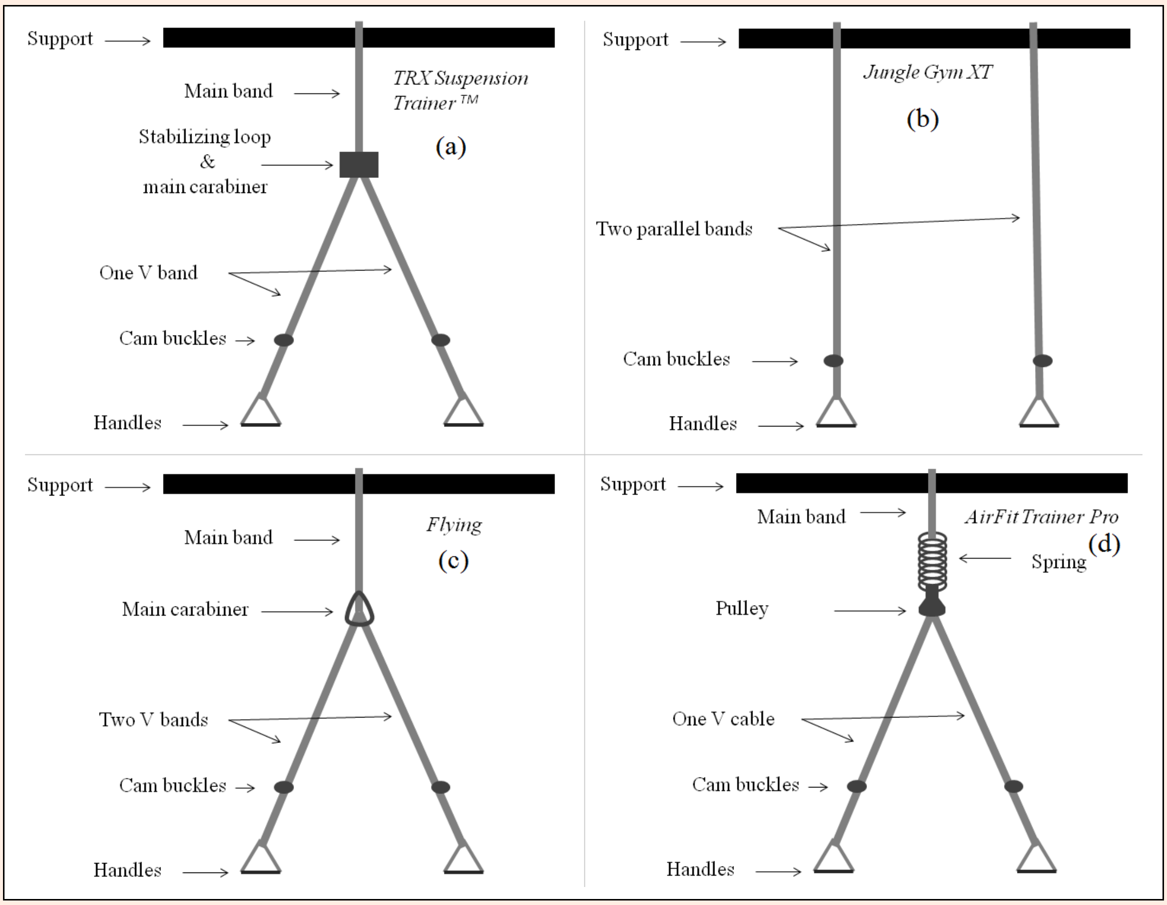

Figure 1. Suspension training equipments: (a) TRX Suspension Trainer, (b) Jungle Gym XT, (c) Flying and (d) AirFit Trainer Pro.

Table 1. Mean (standard error) EMG for each muscle and exercise expressed as percent of each muscle's MVIC (n = 29).

	Floor	TRX Suspension trainer	Jungle Gym XT	Flying	AirFit Trainer Pro	
Triceps Brachii	17.14 (1.31)†‡§‖	37.04 (180)‡‖	24.40 (1.68)*†§‖	34.93 (1.78)*‡‖	47.82 (2.54)*†‡§	F(4,108)=114.212 p<0.001
Upper Trapezius	5.90 (.56)†§‖	15.73 (2.10)*‡§‖	6.35 (.77)†§‖	10.97 (1.54)*†‡‖	20.39 (2.65)*†‡§	F(4,92)=27.184 p<0.001
Anterior Deltoid	26.22 (1.46)†§‖	19.08 (.91)*	22.18 (1.41)§	17.70 (.95)*‡	18.46 (1.24)*	F(4,96)=14.125 p<0.001
Clavicular Pectoralis	29.60 (1.88)‡	31.68 (2.53)‡	41.60 (2.88)*†§‖	30.59 (2.28)‡	27.69 (2.41)‡	F(4,112)=16.504 p<0.001
Rectus Abdominis	23.85 (2.80)†‡§‖	87.98 (8.98)*‖	87.13 (9.27)*‖	97.11 (10.54)*	105.53 (9.84)*†‡	F(4,100)=51.771 p<0.001
Rectus Femoris	7.45 (.72)†‡§‖	11.86 (1.28)*‖	13.43 (1.43)*‖	12.36 (1.21)*‖	19.23 (2.20)*†‡§	F(4,100)=22.013 p<0.001
Erector Lumbar Spinae	2.03 (.14)†‡§‖	3.21 (.24)*‖	3.26 (.23)*‖	3.31 (.24)*‖	4.32 (.32)*†‡§	F(4,112)=50.535 p<0.001
Global	16.75 (.67)†‡§‖	30.50 (1.75)*‖	29.03 (1.72)*‖	30.62 (1.91)*‖	37.76 (2.27)*†‡§	F(4,108)=51.007 p<0.001

Global = mean of the 7 muscles. * =Significant differences compared to the Floor; †= Significant differences compared to the TRX Suspension trainer; ‡=Significant differences compared to the Jungle Gym XT; § =Significant differences compared to the Flying; ‖ =Significant differences compared to the AirFit Trainer Pro

400-Hz cutoff frequency with a fourth-order Butterworth filter. Surface EMG amplitude in the time domain was quantified by using RMS and processed every 100 ms. Mean RMS values were selected for every trial and normalized to the maximum EMG (%MVIC). Global mean of all muscles (i.e., TRICEP, TRAPS, DELT, PEC, ABS, FEM and LUMB) was also calculated (arithmetic mean) and analyzed.

Statistical analyses

Statistical analysis was accomplished using SPSS version 17 (SPSS inc., Chicago, IL, USA). All variables were found to be normally distributed (Shapiro-Wilk's normality test) before data analysis. Results are reported as mean±SE. Statistical comparisons for each muscle among the conditions were performed using Analysis of Variance (ANOVA) with repeated measures. Greenhouse–Geisser correction was used when the assumption of sphericity (Mauchly's test) was violated. Post hoc analysis with Bonferroni correction was used in the case of significant-main effects. Significance was accepted when $p \leq 0.05$.

Results

Statistically significant differences were found for muscle activation (%MVIC) among the different conditions for all muscles. TRICEP and TRAPS EMG signal was significantly greater during the suspended push-up with the pulley system compared to all other conditions. DELT EMG signal was significantly greater with the standard push-up compared to all conditions except the two-anchor suspended push-up. PEC muscle activation was significantly greater with the two-anchor suspended push-up compared to all other conditions. LUMB, FEM and ABS muscle activation was significantly greater during the suspended push-up with the pulley system compared to all other conditions. Complete differences among conditions are represented in Table 1. Graphical representations of the EMG signals for each muscle, ranked from highest to lowest among all exercises, are shown in Figures 2 to 9.

Discussion

In accordance with the hypothesis, the greatest core muscle activation was achieved with the suspension device with a pulley system (i.e., AirFit Trainer Pro), which was considered the most unstable device. However, partly in accordance with the hypothesis, the stable condition only provided the highest muscle activation for the DELT. Suspended push-ups induced greatest activation than standard push-up on the floor, which presented the lowest TRICEP activation, while individually, the suspended

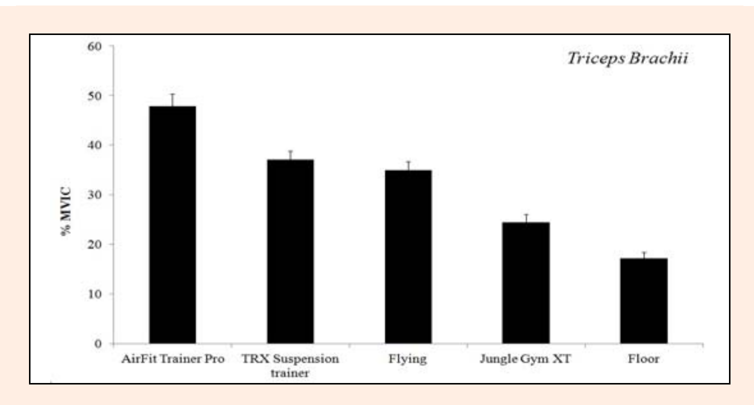

Figure 2. Percentage of maximum voluntary isometric contraction (%MVIC) of triceps brachii under different conditions.

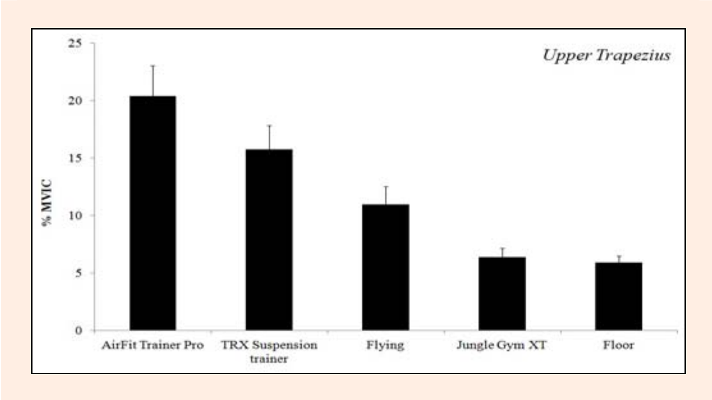

Figure 3. **Percentage of maximum voluntary isometric contraction (%MVIC) of upper trapezius under different conditions.**

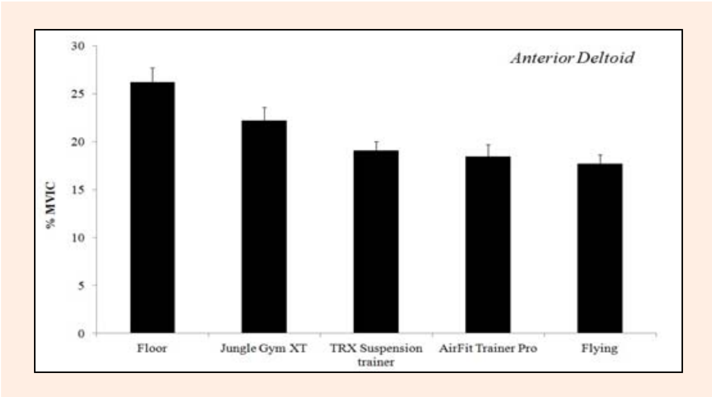

Figure 4. **Percentage of maximum voluntary isometric contraction (%MVIC) of anterior deltoid under different conditions.**

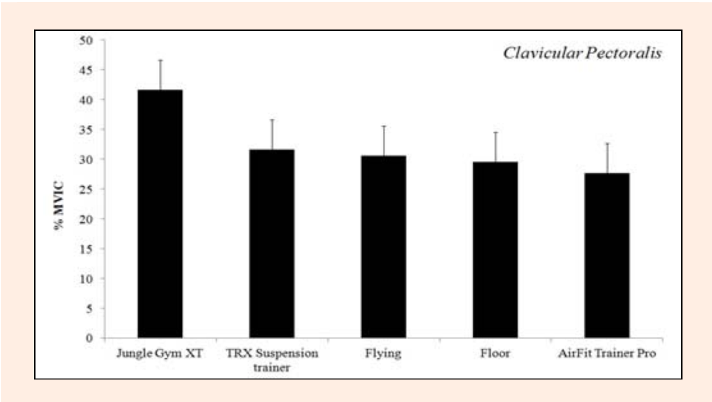

Figure 5. **Percentage of maximum voluntary isometric contraction (%MVIC) of clavicular pectoralis under different conditions.**

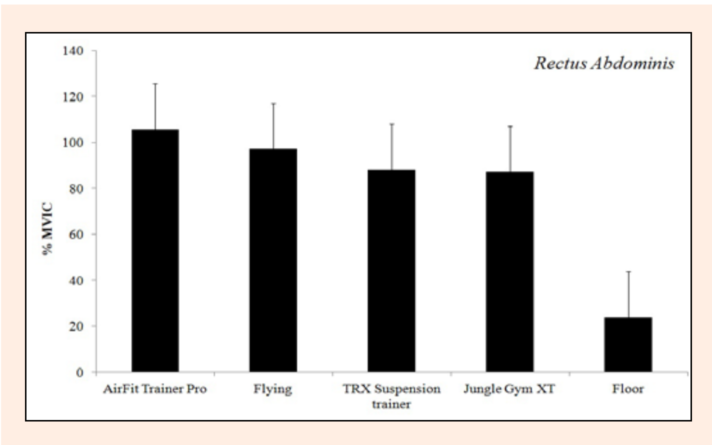

Figure 6. **Percentage of maximum voluntary isometric contraction (%MVIC) of rectus abdominis under different conditions.**

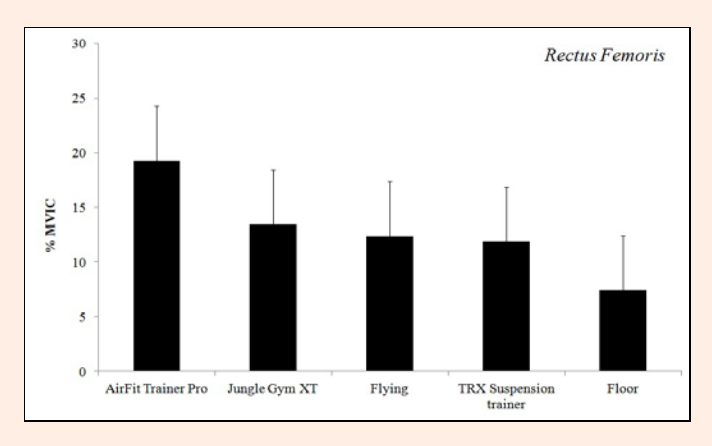

Figure 7. **Percentage of maximum voluntary isometric contraction (%MVIC) of rectus femoris under different conditions.**

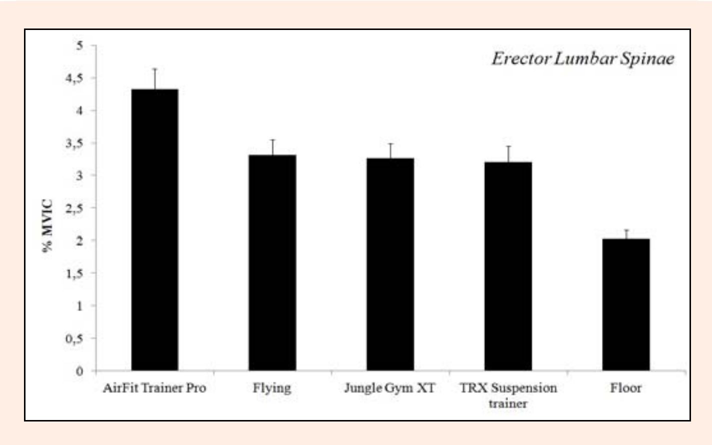

Figure 8. **Percentage of maximum voluntary isometric contraction (%MVIC) of erector lumbar spinae under different conditions.**

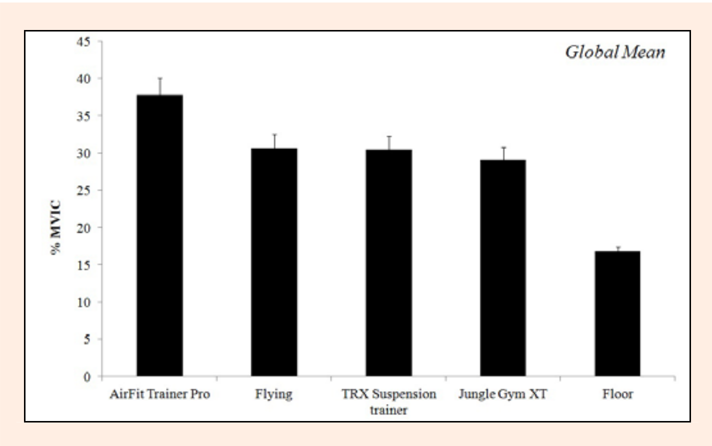

Figure 9. **Percentage of maximum voluntary isometric contraction (%MVIC) of global mean of all muscles (i.e. triceps brachii, upper trapezius, anterior deltoid, clavicular pectoralis, rectus abdominis, rectus femoris and lumbar erector spinae)**

device with a pulley system induced the greatest TRICEP activation. In this line, Lehman et al. (2006) and Anderson et al. (2013) found that TRICEP activation during unstable push-ups was superior to the stable condition. On the other hand, Freeman et al. (2006) showed that performing the push-up with two hands on two balls provoked the same activation levels as a stable push-up. However, it is possible that extent of instability in that study was insufficient to elicit significant differences.

Similar activation patterns were apparent for TRAPS where it seems that unstable conditions may provide a greater challenge than stable conditions. The suspended device with a pulley system elicited over triple TRAPS activation compared with the two parallel band system with independent anchors and the standard push-up on the floor, probably due to the greater unilateral movement allowed and the scapular synergist stabilizer role of this muscle (Lear and Gross, 1998). In accordance, unilateral maintained push-up on a medicine ball showed greater activation of the TRAPS compared to a stable surface (de Oliveira et al., 2008).

Despite there being no significant DELT activation differences between the standard push-up on the floor and the two-anchor suspended push-up, the condition provided by the stable push-up was the only one that caused greater activation than the condition induced by the one-anchor devices (i.e., Flying, TRX Suspension Trainer and the Airfit Trainer Pro). Thus, results suggest that for DELT, a more stable condition may provide a greater or similar extent of activation as more unstable conditions. Consistent with this affirmation, Freeman et al. (2006) found that push-ups on the ground provide similar DELT activation as the same exercise performed with hands on two balls.

The PEC muscle showed significantly increased activation with the two-anchor suspended push-up in comparison with the other conditions. A 20% of MVIC higher activation has been reported for a two ball push-up versus a standard version (Freeman et al., 2006). In contrast, no significant differences were found in favour of pectoralis major activation during push-up exercises on a Swiss ball compared with a stable condition (Lehman et al., 2006). Authors stated that absence of changes in muscle activation of the pectoralis major may be due to its role as prime mover and to a less extent as stabilizer (Lehman et al., 2006), and suggested that moderate, rather than excessive levels of instability, are required to increase activation in pectoralis major muscle (Behm and Colado, 2012; Behm et al., 2010). Other reasons that may lead to different muscle activity is the height of the feet during the exercise and the use of shoulder width or wider hand positions, although recent research does not show any difference in pectoralis major activation during a push-up with these hand positions (Youdas et al., 2010). In addition, it is noteworthy that participants' characteristics such as training experience may play an important role in muscle activation levels (Wahl and Behm, 2008).

If we take into consideration the DiGiovine´s scheme (DiGiovine et al., 1992), LUMB and FEM activation levels are classified as low (i.e., <20% of MVIC). Previous studies reported low LUMB activation rates during push-ups on unstable conditions (Freeman et al., 2006; Beach et al., 2008; Anderson et al., 2013) and during similar exercise positions such as a press-up (Marshall and Murphy, 2005) or prone bridge (Lehman et al., 2005, Kang et al., 2012). These findings suggest that suspended devices provoke a safe amount of muscle activation for the lumbar spine (Escamilla et al., 2010) since excessive muscle activity in the lumbar paraspinals has been related to high compressive and shear forces in this zone (Juker et al., 1998). Low activation levels may be appropriate for LUMB muscle (Behm and Colado, 2012) due to their high type I fiber proportion (Behm et al., 2010) and the prevalent role of muscular endurance for daily functional tasks (McGill, 2001). Higher FEM activation has been suggested to cause greater lumbar lordosis (Sundstrup et al., 2012) and may increase the risk of low back pain (Youdas et al., 2008). In our study, the suspended device with the pulley system achieved the greater FEM activation, perhaps due to greater strength requirements to avoid falling and maintain adequate posture and exercise technique. Although it is unknown how much FEM muscle activity is related to greater anterior tilt and an increased lumbar lordosis, caution should be used with some individuals because of the increased low-back injury risk with suspended push-ups (Beach et al., 2008; McGill et al., 2014).

The greatest muscle activity of all muscles was achieved for the ABS muscle. The suspended device with the pulley system showed greater activation levels than all conditions but did not differ from Flying. Nevertheless, ABS activation levels were very high during all suspended conditions according to DiGiovine´s (1992) classification. Similarly, Beach et al. (2008) reported greater ABS activation during the suspended push-ups compared with regular push-ups. Likewise, results showing instability-induced higher activation were demonstrated when performing push-ups (Freeman et al., 2006; Anderson et al., 2013), push-up variations such as a press up on top (Marshall and Murphy, 2005) or a push-up plus (Lehman et al., 2006), and a different exercise with similar position to a prone bridge (Lehman et al., 2005, Kang et al., 2012).

Conclusion

Coaches, athletes and fitness enthusiasts can use the present information to select the optimal suspension training device and to establish an intensity push-up progression based on the reported extent of muscle activation. It should be noted that greater activation of the TRICEP, TRAPS, LUMB and FEM can be achieved with more unstable suspension devices as a one-anchor system with a pulley. However, if greater activation is sought for the DELT and PEC, it can be achieved with more stable conditions. In fact, a parallel band system with two anchors is the best option to increase PEC muscle activation whereas the suspended push-ups do not suppose an additional advantage to increase DELT muscle activity. All the tested push-up suspension systems effectively enhance ABS activation.

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Key points

- Compared with standard push-ups on the floor, suspended push-ups increase core muscle activation.
- A one-anchor system with a pulley is the best option to increase TRICEP, TRAPS, LUMB and FEM muscle activity.
- More stable conditions such as the standard push-up or a parallel band system provide greater increases in DELT and PEC muscle activation.
- A suspended push-up is an effective method to achieve high muscle activity levels in the ABS.

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Muscle Activity Levels in Upper-Body Push Exercises With Different Loads and Stability Conditions

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Abstract

Background: Exercises that aim to stimulate muscular hypertrophy and increase neural drive to the muscle fibers should be used during rehabilitation. Thus, it is of interest to identify optimal exercises that efficiently achieve high muscle activation levels. **Objective:** The purpose of this study was to compare the muscle activation levels during push-up variations (ie, suspended push-ups with/without visual input on different suspension systems, and push-ups on the floor with/without additional elastic resistance) with the bench press exercise and the standing cable press exercise both performed at 50%, 70%, and 85% of the 1-repetition maximum. **Methods:** Young fit male university students (N = 29) performed 3 repetitions in all conditions under the same standardized procedures. Average amplitude of the electromyogram (EMG) root mean square for the rectus abdominis, external oblique, sternocostal head of the pectoralis major, anterior deltoid, long head of the triceps brachii, upper trapezius, anterior serratus, and posterior deltoid was recorded. The EMG signals were normalized to the maximum voluntary isometric contraction. The EMG data were analyzed with repeated-measures analysis of variance with a Bonferroni post hoc. **Results and Conclusions:** Elastic-resisted push-ups induce similar EMG stimulus in the prime movers as the bench press at high loads while also providing a greater core challenge. Suspended push-ups are a highly effective way to stimulate abdominal muscles. Pectoralis major, anterior deltoid, and anterior serratus are highly elicited during more stable pushing conditions, whereas abdominal muscles, triceps brachii, posterior deltoid, and upper trapezius are affected in the opposite manner.

Keywords: electromyogram; intensity; unstable; trunk; exercise

Introduction

Intensity is a key factor in muscle strength progressions[1] and electromyogram (EMG) levels often are used as an indicator of exercise intensity.[2] Exercises that aim to increase neural drive to the muscle fibers should be used during rehabilitation[2] and athletic conditioning.[3] As such, it is of interest to identify optimal exercises to achieve high muscle activation levels to stimulate muscle hypertrophy and increase muscle strength.[2] It is generally assumed that exercises that produce higher EMG signal amplitudes generate larger effects on muscle strength.[2,4] It has been stated that neuromuscular activation should be at least in the range of 40% to 60% of the maximum voluntary isometric contraction (MVIC) to stimulate muscle strength adaptations.[2] However, it is difficult to establish a muscle activation threshold because it depends on several variables,

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including an individual's training experience[5] and the EMG normalization technique that is used.[6] Moreover, EMG levels required to induce resistance training adaptations such as muscular endurance, hypertrophy, or maximal strength have not been established.

Pushing exercises are a classic element of strength training programs,[1,7] and their movement is related to daily activities.[8] A typical pushing exercise to strengthen the upper body is the bench press.[1] Other pushing exercises that have been compared with the bench press are push-ups[9] and the standing cable press.[10]

Santana et al[10] demonstrated that the standing cable press exercise provides higher instability and core muscle activation than the bench press but provides less activation in the primary movers. Biomechanically similar to the bench press,[9] traditional push-ups are used as an alternative to classic weight-lifting exercises[11] for upper-body strengthening.[12] Push-ups also have been used in testing[13–15] and upper-extremity injury rehabilitation.[16] The ability to increase intensity through several modifications has made the push-up a popular exercise. Push-up progressions may involve performing the exercise with additional resistance or in unstable conditions. One option to increase resistance is to employ elastic resistance bands.[17] However, their use during push-ups has not been investigated. Options to induce instability include sensorial manipulations (eg, closing the eyes)[18] or performing suspended push-ups.[8,19] Nevertheless, no EMG data have been reported regarding push-ups with different types of suspension systems or with sensorial manipulations. In addition, there is no information about the differences in activation of the prime movers that may be provided by suspended versus stable push-ups.

The aforementioned push-up variations may be a feasible way to produce muscle adaptations without training facilities if sufficient intensities are achieved. As strength adaptations are used to enhance athletic performance and improve musculoskeletal health,[3] the effectiveness of alternative training methods should be investigated.[4] However, as far as we are aware, a direct comparison between push-up variations and other push exercises (eg, bench press, standing cable press) performed at different intensities has not been performed. Thus, the purpose of this study was to compare the muscle activation levels during a bench press exercise and a standing cable press exercise, both performed at 50% of the 1 repetition maximum (1RM), 70% of the 1RM, and 85% of the 1RM, with suspended push-ups under different stability conditions (ie, suspended push-ups with/without visual input and different suspension systems), and push-ups on the floor with/without additional elastic resistance.

Methods

Experimental Approach to the Problem

Twenty-nine volunteers took part in a descriptive laboratory study with a repeated measures design assessment and performed 2 different sessions. In the first session, the subjects were familiarized with the movements and protocol, and in the second session they performed 11 different conditions. Surface EMG signals were recorded for the following muscles: rectus abdominis (ABS), external oblique (OBLIQ), sternocostal head of the pectoralis major (PEC), anterior deltoid (ADELT), long head of the triceps brachii (TRICEP), upper trapezius (TRAPS), anterior serratus (SERRA), and posterior deltoid (PDELT). The data obtained were normalized by using the mean root mean square (RMS) values during the MVIC and expressed as a percentage of the maximum EMG. The study design attempted to answer the following research question: Do the different push-up variations produce EMG activity similar to the bench press and the standing cable press performed at different intensities?

Participants

Young fit male university students (N = 29; resistance training experience: 2.5 ± 2.0 years; age: 22.6 ± 2.6 years; height: 176.0 ± 4.4 cm; weight: 74.6 ± 6.7 kg; body fat percentage: 11.0 ± 2.7%; biacromial (shoulder) width: 42.0 ± 2.1 cm; biacromial width +50%: 62.2 ± 3.1 cm) voluntarily participated in this study. The number of participants chosen was calculated based on an effect size of 0.25 standard deviation with an α level of 0.05 and power at 0.80. Participants' training status was considered to be advanced because they had a minimum of 1 year of resistance training experience, performing ≥ 3 sessions per week at moderate-to-high intensity.[7] No participant included in this study had musculoskeletal pain, neuromuscular disorders, or any form of joint or bone disease. All participants signed an institutional informed consent form before starting the protocol, and the institutional review board approved the study. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

Procedures

Each participant took part in 4 sessions: 1 familiarization session, 2 repetition maximum (RM) estimation sessions, and 1 experimental session. All sessions were performed at the same hour in the morning separated by a 2-day interval.

Several restrictions were imposed on the volunteers: no food, drinks, or stimulants (eg, caffeine) to be consumed 3 to 4 hours before the sessions, and no physical activity more intense than daily activities 12 hours before the exercises. They were instructed to sleep > 8 hours the night before data collection. All measurements were made by the same investigators and were always conducted in the same sports facility that had an ambient temperature of 20 °C (68°F). The study was done during the spring.

Familiarization Session

During the familiarization session, the participants were familiarized with the different exercises and conditions, movement amplitude, body position, and cadence of movement that would later be used during data collection. Participants practiced each exercise, typically 1 to 3 times, until they felt confident and the researcher was satisfied that the correct technique had been achieved. Height (IP0955, Invicta Plastics Limited, Leicester, England), body mass, body fat percentages (Tanita model BF-350), and biacromial width were obtained according to the protocols used in previous studies.[20]

1RM Estimation Sessions

Before the 1RM estimation, subjects performed mobility drills without ballistic movements to warm up. Participants performed two 1RM tests (ie, bench press and a standing cable press) in a counterbalanced order, separated by 2 days between each 1RM testing session. The 2 activities were performed with the same technique and body position that would later be used during data collection; 3 to 5 attempts were performed to measure each 1RM in order to avoid fatigue, which would compromise the accuracy of the test.[14]

The measurement of the 1RM for the bench press was performed on a Smith machine according to the protocol described by Baechle et al.[7] Subjects were positioned supine with the head and trunk supported by the bench, the knees bent, the feet flat on the bench, the elbow flexed 90°, and the shoulder abducted 45°. At the same time, a researcher was located at the head end of the bench during the test to assist in raising the bar on a failed attempt and to help the participant place the bar back on the rack.[14]

The measurement of the 1RM for the standing cable press was performed with the feet in parallel at shoulder width. The position of the feet was marked and situated at 60 cm from the machine. The pressing load was applied parallel to the ground, with the elbow flexed 90° and the shoulder abducted 45°. With the exception of the arm, no body segment traveled beyond the toes. To prevent this from occurring, researchers used a cross line auto laser level, fixated with a tripod (Black and Decker LZR6TP, New Britain, CT) to provide visual feedback. Thus, participants achieved their 1RM while keeping a stable position during the movement, with knees slightly bent. Resistance and rest periods between attempts were progressively increased according to the 1RM bench press protocol established by the National Strength and Conditioning Association (NSCA).[7] Assessment of 1RM enabled calculation of the precise training loads used during the experimental session in press exercises (50%, 70%, and 85% of 1RM).

Experimental Session

The protocol started with the preparation of participants' skin, and followed by electrode placement, MVIC collection, and exercise performance. Hair was removed with a razor from the skin overlying the muscles of interest, and the skin was then cleaned by rubbing with cotton wool dipped in alcohol for the subsequent electrode placement, positioned according to the recommendations of Cram et al[6] on the ABS, OBLIQ, PEC, ADELT, TRICEP, TRAPS, SERRA, and posterior PDELT on the dominant side of the body. Pre-gelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S, Medicotest, Olstykke, Denmark) were placed with an interelectrode distance of 25 mm. The reference electrode was placed between the active electrodes, approximately 10 cm away from each muscle, according to the manufacturer's specifications. Once the electrodes were placed, participants performed 1standard push-up on the floor in order to check signal saturation. All signals were acquired at a sampling frequency of 1 kHz, amplified and converted from analog to digital. All records of myoelectrical activity (in microvolts) were stored on a hard drive for later analysis. To acquire the surface EMG signals produced during exercise, an ME6000P8 (Mega Electronics, Ltd., Kuopio, Finland) biosignal conditioner was used.

Prior to the dynamic exercises described below, two 5-second MVICs were performed for each muscle and the trial with the higher EMG was selected.[17] Participants performed 1 practice trial to ensure that they understood the task. One minute of rest was given between each MVIC, and standardized verbal encouragement was provided to motivate all participants to achieve maximal muscle activation. Positions during the MVICs were based on standardized muscle testing procedures for the (1) ABS,[21] (2) OBLIQ,[21] (3) PEC,[9,22] (4) ADELT,[23] (5) TRICEP,[24] (6) TRAPS,[23] (7) SERRA,[23] and (8) PDELT,[24] and were performed against a fixed immovable resistance (ie, Smith machine). The corresponding testing procedures were as follows: (1) curl up at 40° with arms on chest and pressing against the bar with the participant lying on the bench with the feet flat on the bench and the knees bent at 90°; (2) in the same position, pressing against the bar in an oblique direction; (3) bench press with a grip at a biacromial width distance +50%, the shoulder abducted at 45°, and the feet flat on the bench; (4) deltoid flexion at 90° in a seated position with erect posture and no back support; (5) forearm extension with elbows at 90° in a seated position with erect posture and no back support; (6) deltoid abduction at 90° in a seated position with erect posture and no back support; (7) shoulder flexed to 125° as resistance is applied above the elbow and at the inferior angle of the scapula, with the participant seated with erect posture and no back support; and (8) with the resistance above the elbow, the participant pressing against the bar in the direction of abduction and slight flexion, in a seated position with erect posture and no back support.

The participants started all the exercises in an extended arm position with forearms and wrists pronated, feet at a biacromial (shoulder) width, and the fingers flexed. In the flexed position, the forearm and wrists were kept pronated, whereas the elbow was flexed 90° and the shoulder abducted 45°. A cross line auto laser level was fixated with a tripod (Black and Decker LZR6TP, New Britain, CT) and used as visual feedback for researchers in connection with the requested elbow and shoulder joint positioning during exercises. The hips and spine were maintained neutral during all repetitions. Participants performed the following 11 conditions, randomly assigned, with a 2-minute interval between them: 1 and 2, suspended push-up with eyes open on 2 different suspension systems; 3, suspended push-ups without visual input; 4, push-ups on the floor with elastic resistance; 5, standard push-up on the floor; 6, 7, and 8, bench press at 50%, 70%, and 85% 1RM with the Smith machine; and 9, 10, and 11, standing cable press at 50%, 70%, and 85% 1RM. Each participant performed 3 consecutive repetitions in all conditions to avoid the influence of fatigue on the subsequent condition.[17] A 2-second rate for descent and ascent of each repetition was maintained by a 30-Hz metronome (Ableton Live 6, Ableton AG, Berlin, Germany) to standardize the speed of movement. A standardized grip width of biacromial width distance +50% (distance in centimeters between the tips of right and left third digits) was maintained during all the conditions. Visual feedback was given to the participants in order to maintain the range of movement and hand distance during the data collection. In addition, verbal feedback was provided to the participants for the same purpose, especially during the suspended push-ups without visual input. A trial was discarded and repeated if participants were unable to perform the exercise with the correct technique.

Exercise Equipment

The push-up exercise was performed under 5 conditions: (1) suspended push-up with eyes open on a V-shaped system (TRX Suspension Trainer, TRX, San Francisco, CA), (2) suspended push-up without visual input on the aforementioned system, (3) suspended push-up with eyes open on a V-shaped system with a pulley (AirFit Trainer Pro, PurMotion, Pelham, AL), (4) standard push-up on the floor, and (5) push-up on the floor with elastic resistance. The main difference between the suspension systems is that the system with a pulley has a main band supported by a spring and a V cable with a pulley in the middle, providing reduced friction, the possibility to perform unilateral movements, and thus allows greater unilateral disruptions. The band length in the suspension devices was adjusted for the hands to be at 10 cm from the floor during all repetitions. In addition, the feet were elevated 10 cm from the floor during the suspended push-up. In the suspended push-up without visual input, the eyes of the participants were covered.

For the push-up with elastic resistance, a gold resistance band was used (Thera-band, Hygenic Corporation, Akron, OH). To provide greater resistance,[25] the elastic band grip was performed at 70 cm of the total band length. A researcher assistant helped the participants to put the band behind their back with the aforementioned length. Then, participants stretched the band so that they could perform the exercise with the proper grip width (ie, biacromial width distance +50%). Regarding the bench press and the standing cable press, conditions were performed using the exercise techniques and positions that have been previously mentioned in the testing and data collection sections.

Data Analysis

All surface EMG signal analyses were performed using Matlab 7.0 (Mathworks Inc., Natick, MA). Surface EMG signals related to isometric exercises were analyzed by using the 3 middle seconds of the 5-second isometric contraction. The EMG signals of the dynamic exercises were analyzed by taking the average of the entire 3 repetitions. All signals were bandpass filtered at a 20- to 400-Hz cutoff frequency with a fourth-order Butterworth filter. Surface EMG amplitude in the time domain was quantified by using RMS and processed every 100 ms. Mean RMS values were selected for every trial and normalized to the maximum EMG (%MVIC). Mean values of the %MVIC of the ABS, OBLIQ, PEC, ADELT, TRICEP, TRAPS, SERRA, and PDELT, and the global mean of all muscles were also calculated and analyzed.

Statistical Analyses

Statistical analysis was accomplished using SPSS version 17 (SPSS Inc., Chicago, IL). All variables were found to be normally distributed (Shapiro-Wilk's normality test) before data analysis. Results are reported as mean ± standard error. Statistical comparisons for each muscle among the conditions were performed using analysis of variance (ANOVA) with repeated measures. Greenhouse–Geisser correction was used when the assumption of sphericity (Mauchly's test) was violated. Post-hoc analysis with Bonferroni correction was used in the case of significant main effects. Significance was accepted at $P \leq 0.05$.

Results

Statistically significant differences were found for the 1RM testing loads (Table 1) and for muscle activation (%MVIC) among the different conditions in all muscles.

The ABS EMG signal was significantly greater with the suspended push-ups compared with all other conditions. The OBLIQ activation was significantly greater with the suspended push-ups compared with all other exercises except during the eyes-open suspended push-up with the V-shaped system, which showed no significant difference compared with the elastic-resisted push-up. The PEC muscle activation was significantly greater with the bench press at 85% 1RM compared with all other conditions. The TRICEP EMG signal was significantly greater during the suspended push-up with the pulley system compared with all other conditions. The ADELT EMG signal was significantly greater with the bench press at 85% 1RM compared with all conditions except the elastic-resisted push-up. The TRAPS activity was significantly greater with the eyes-open suspended push-up with the V-shaped system compared with all conditions except the 2 push-ups on the floor, the other suspended push-ups, the bench press at 85% 1RM, and the standing cable press at each intensity. Push-ups on the floor elicited the highest number of significantly greater EMG signals for the SERRA compared with all conditions except the bench press at 70% and 85% 1RM. The PDELT EMG signal was significantly greater with the suspended push-up with the pulley system compared with all other conditions. Complete differences among conditions are indicated in Table 2. Graphical representations of ABS, OBLIQ, PEC, ADELT, TRICEP, TRAPS, SERRA, and PDELT EMG signals, ranked from highest to lowest among all exercises, are shown in Figures 1, 2, 3, 4, 5, 6, 7 and 8, and the relative intensities separated by different EMG levels are shown in Table 3.

Table 1. 1RM Testing Loads

	Mean	SD	*P* value
1RM bench press, kg	91.59[a]	13.69	< 0.001
1RM standing cable press, kg	13.00	1.75	

[a]Significant differences between tests.
Abbreviation: 1RM, 1 repetition maximum.

Discussion

The aim of this study was 2-fold: (1) to evaluate neuromuscular activation during different upper-body pushing exercises and conditions, and (2) to compare muscle activation levels between different push-up variations and 3 different intensities for the bench press and standing cable press. A discussion of the main findings follows.

This investigation demonstrated that 1RM loads significantly decreased during the standing cable press compared with the bench press. Findings are in line with those of Santana et al,[10] who found that the lower postural control during the standing cable press determined the amount of the load that was moved.

The highest numerical EMG values of the study were achieved in the ABS and OBLIQ. In this regard, suspended push-ups were the most efficient to reach elevated activity levels, followed by push-ups on the floor and press exercises. High abdominal activation levels were reported previously during suspended push-ups.[8,19] Moreover, other studies showed greater ABS activity during the unstable counterpart of push-ups.[26,27] Although EMG data showed no difference between the different suspended push-up conditions, greater unilateral disruptions and closing the eyes appear to be variations that reach even higher activation levels in the OBLIQ compared with the push-up with elastic resistance. In contrast with previous findings,[10] our study showed that abdominal activation levels were similar during the 2 press exercises. However, in the study conducted by Santana et al,[10] participants performed a 1-arm press, which could elicit a higher amount of core muscle activation as has been recently corroborated.[28]

A previous study showed that elastic resistance may yield high EMG levels.[4] This is supported by the current results for the push-up with elastic resistance, which demonstrate similar PEC activation levels as the bench press at 70% 1RM and greater activation than the other push-up versions.

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Table 2. Mean and SE Electromyogram for Each Muscle and Exercise Expressed as Percent of Each Muscle's MVIC (N = 29)

Muscle	Standard Push-Up (A)	Elastic-resisted Push-Up (B)	Suspended Push-Up With Closed Eyes (C)	Suspended Push-Up With Open Eyes (D)	Suspended Push-Up With Pulley System (E)	Bench Press 50% 1RM (F)	Bench Press 70% 1RM (G)	Bench Press 85% 1RM (H)	Standing Cable Press 50% 1RM (I)	Standing Cable Press 70% 1RM (J)	Standing Cable Press 85% 1RM (K)
Rectus abdominis	13.31	15.48	57.08	60.04	65.82	1.84	3.33	4.65	2.00	2.17	3.34
	(1.63)[c-k]	(1.72)[c-k]	(8.38)[a,b,f-k]	(10.20)[a,b,f-k]	(10.12)[a,b,f-k]	(0.30)[a-e,g,h]	(0.53)[a-f]	(0.62)[a-f,i]	(0.28)[a-e,h,k]	(0.21)[a-e]	(0.44)[a-e,i]
External oblique	25.14	30.62	56.02	55.28	74.61	4.16	5.18	5.80	4.55	5.67	6.05
	(3.80)[c-g,i]	(4.06)[c,e,f-k]	(6.55)[a,b,f-k]	(7.43)[a,f-k]	(6.67)[a,b,f-k]	(0.73)[a-e,h]	(0.62)[a-e]	(0.66)[b-f]	(1.20)[b-e]	(1.22)[b-e]	(1.04)[b-e]
Pectoralis major	23.58	41.00	30.57	29.46	22.80	24.63	40.48	52.91	4.11	5.49	7.03
	(1.74)[b,g-k]	(2.46)[a,c-f,h-k]	(2.00)[b,e,h-k]	(1.70)[b,e,g-k]	(1.61)[b-d,g-k]	(2.25)[b,g-k]	(2.86)[a,d,e,f,h-k]	(3.28)[a-g,i-k]	(0.43)[a-h,k]	(0.52)[a-h]	(0.63)[a-j]
Anterior deltoid	29.68	42.86	17.79	16.42	14.45	23.79	33.91	44.18	8.44	9.61	9.87
	(2.56)[b-e,h-k]	(2.96)[a,c-f,i-k]	(2.06)[a,b,g-j]	(1.41)[a,b,g-k]	(1.31)[a,b,g-i]	(2.26)[b,g-k]	(2.64)[c-f, h-k]	(2.69)[a,c-g,i-k]	(0.69)[a-h]	(0.93)[a-d,f-h]	(0.92)[a,b,d,f-h]
Triceps brachii	13.99	19.19	30.54	32.95	41.14	10.92	16.53	22.97	1.07	1.28	1.39
	(1.54)[b-e,h-k]	(1.72)[a,c-f,i-k]	(2.87)[a,b,e,f,g,i-k]	(3.41)[a,b,e,f,g,i-k]	(3.66)[a-d,f-k]	(1.07)[b,g-k]	(1.47)[c-f,h-k]	(2.13)[a,e,f,g,i-k]	(0.12)[a-h,k]	(0.13)[a-i]	(0.14)[a-j]
Upper trapezius	5.28	7.77	8.50	9.40	10.89	2.82	4.05	5.32	4.26	4.76	4.30
	(0.65)[f]	(1.00)[f]	(1.22)[f]	(1.35)[f,g]	(2.07)	(0.31)[a-d,g,h]	(0.39)[d,f]	(0.64)[f]	(0.69)	(0.80)	(0.73)
Anterior serratus	24.38	26.48	13.68	13.11	9.83	15.76	21.82	27.02	9.26	11.00	11.24
	(2.29)[c-f,i-k]	(1.92)[c-f,i-k]	(1.05)[a,b,e]	(1.32)[a,b,e,h]	(1.00)[a-d,h]	(2.01)[a,b,h]	(3.00)[i]	(3.45)[d,e,f,i-k]	(1.21)[a,b,g,h]	(1.39)[a,b,h]	(1.18)[a,b,h]
Posterior deltoid	2.50	3.31	4.11	5.26	9.95	1.85	2.47	3.46	0.90	1.26	1.26
	(0.19)[b,e,f,h,j]	(0.23)[a,e,f,g,i-k]	(0.43)[e,f,i-k]	(0.69)[e,f,g,i-k]	(1.37)[a-d,f-k]	(0.15)[a-e,g-i]	(0.15)[b,d-f,h-k]	(0.24)[a,e,f,g,i-k]	(0.06)[a-h]	(0.15)[a-e,g,h]	(0.16)[b-e,g,h]
Global	18.82	26.12	31.10	33.10	36.23	11.83	18.00	23.76	5.13	5.97	6.70
	(1.23)[b-f,i-k]	(1.41)[a,c–g,i–k]	(1.79)[a,b,f,g,i-k]	(2.14)[a,b,f,g,i-k]	(2.41)[a,b,f-k]	(0.67)[a-e,g-k]	(1.00)[b-f,h-k]	(1.29)[e,f,g,i-k]	(0.27)[a-h,j,k]	(0.37)[a-i]	(0.36)[a-i]
Ratio of anterior	3.04	2.42	1.41	1.25	0.78	5.80	5.33	4.80	1.78	2.26	1.92
serratus/upper trapezius	(0.32)[d,e]	(0.24)[e]	(0.18)[h]	(0.20)[a,f,h]	(0.11)[a,b,f-h]	(1.03)[d,e]	(0.96)[e]	(0.66)[c-e]	(0.33)	(0.54)	(0.36)

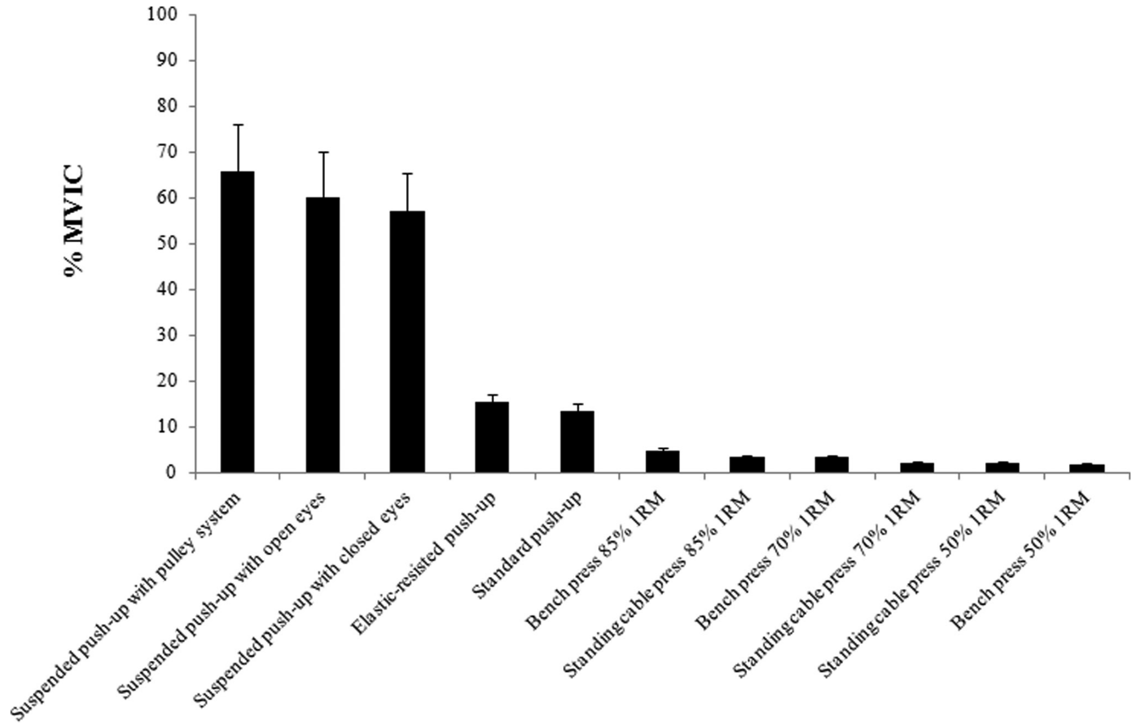
[a]Significant differences compared with the standard push-up.
[b]Significant differences compared with the elastic-resisted push-up.
[c]Significant differences compared with the suspended push-up with closed eyes.
[d]Significant differences compared with the suspended push-up with open eyes.
[e]Significant differences compared with the suspended push-up with pulley system.
[f]Significant differences compared with the bench press 50% 1RM.
[g]Significant differences compared with the bench press 70% 1RM.
[h]Significant differences compared with the bench press 85% 1RM.
[i]Significant differences compared with the standing cable press 50% 1RM.
[j]Significant differences compared with the standing cable press 70% 1RM.
[k]Significant differences compared with the standing cable press 85% 1RM.
Abbreviations: 1RM, 1 repetition maximum; MVIC, percentage of maximum voluntary isometric contraction; SE, standard error.

Table 3. Relative Intensities Separated by Different Electromyogram Levels

Muscle	Very High (> 60% MVIC)	High (41%–60% MVIC)	Moderate (21%–40% MVIC)	Low (0%–20% MVIC)
Rectus abdominis	Suspended push-up with open eyes, suspended push-up with pulley system	Suspended push-up with closed eyes		Standard push-up, elastic-resisted push-up, bench press 50% 1RM, bench press 70% 1RM, bench press 85% 1RM, standing cable press 50% 1RM, standing cable press 70% 1RM, standing cable press 85% 1RM
External oblique	Suspended push-up with pulley system	Suspended push-up with open eyes, suspended push-up with closed eyes	Standard push-up, elastic-resisted push-up	Bench press 50% 1RM, bench press 70% 1RM, bench press 85% 1RM, standing cable press 50% 1RM, standing cable press 70% 1RM, standing cable press 85% 1RM
Pectoralis major		Elastic-resisted push-up, bench press 70% 1RM, bench press 85% 1RM	Suspended push-up with closed eyes, standard push-up, suspended push-up with open eyes, suspended push-up with pulley system, bench press 50% 1RM,	Standing cable press 50% 1RM, standing cable press 70% 1RM, standing cable press 85% 1RM
Anterior deltoid		Elastic-resisted push-up, bench press 85% 1RM	Standard push-up, bench press 50% 1RM, bench press 70% 1RM	Standing cable press 50% 1RM, standing cable press 70% 1RM, standing cable press 85% 1RM, suspended push-up with pulley system, suspended push-up with closed eyes, suspended push-up with open eyes
Triceps brachii		Suspended push-up with pulley system	Suspended push-up with closed eyes, suspended push-up with open eyes, bench press 85% 1RM	Standard push-up, elastic-resisted push-up, bench press 50% 1RM, bench press 70% 1RM, standing cable press 50% 1RM, standing cable press 70% 1RM, standing cable press 85% 1RM
Upper trapezius				Standard push-up, elastic-resisted push-up, bench press 50% 1RM, bench press 70% 1RM, bench press 85% 1RM, suspended push-up with closed eyes, suspended push-up with open eyes, suspended push-up with pulley system, standing cable press 50% 1RM, standing cable press 70% 1RM, standing cable press 85% 1RM
Anterior serratus			Standard push-up, elastic-resisted push-up, bench press 70% 1RM, bench press 85% 1RM	Bench press 50% 1RM, suspended push-up with closed eyes, suspended push-up with open eyes, suspended push-up with pulley system, standing cable press 50% 1RM, standing cable press 70% 1RM, standing cable press 85% 1RM
Posterior deltoid				Standard push-up, elastic-resisted push-up, bench press 50% 1RM, bench press 70% 1RM, bench press 85% 1RM, suspended push-up with closed eyes, suspended push-up with open eyes, suspended push-up with pulley system, standing cable press 50% 1RM, standing cable press 70% 1RM, standing cable press 85% 1RM

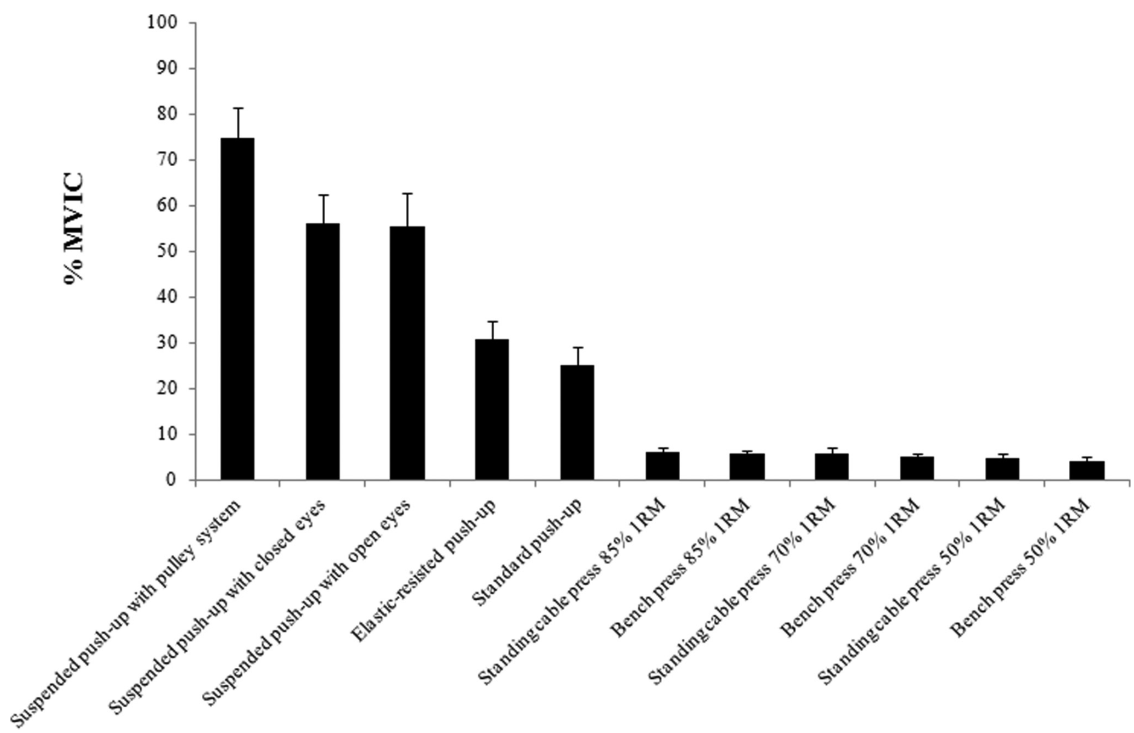
Abbreviations: MVIC, maximum voluntary isometric contraction; 1RM, 1 repetition maximum.

Figure 1. Rectus abdominis normalized mean (± SD) electromyographic signal among exercises. Graphical representations are provided to improve reading and provide an easy way to understand the intensity of the different conditions, since exercises are ranked from highest to lowest muscular activation. Mean is the column and SD is the bar.



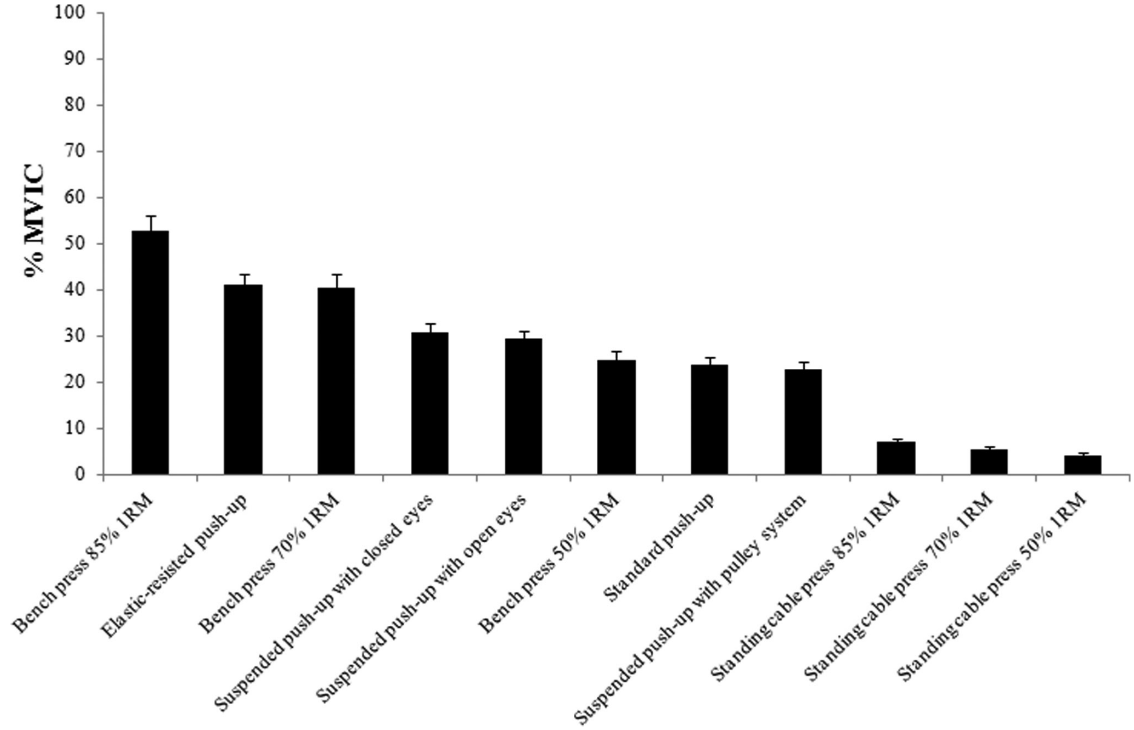
Abbreviation: %MVIC, percentage of maximum voluntary isometric contraction.

Figure 2. External oblique normalized mean (± SD) electromyographic signal among exercises.



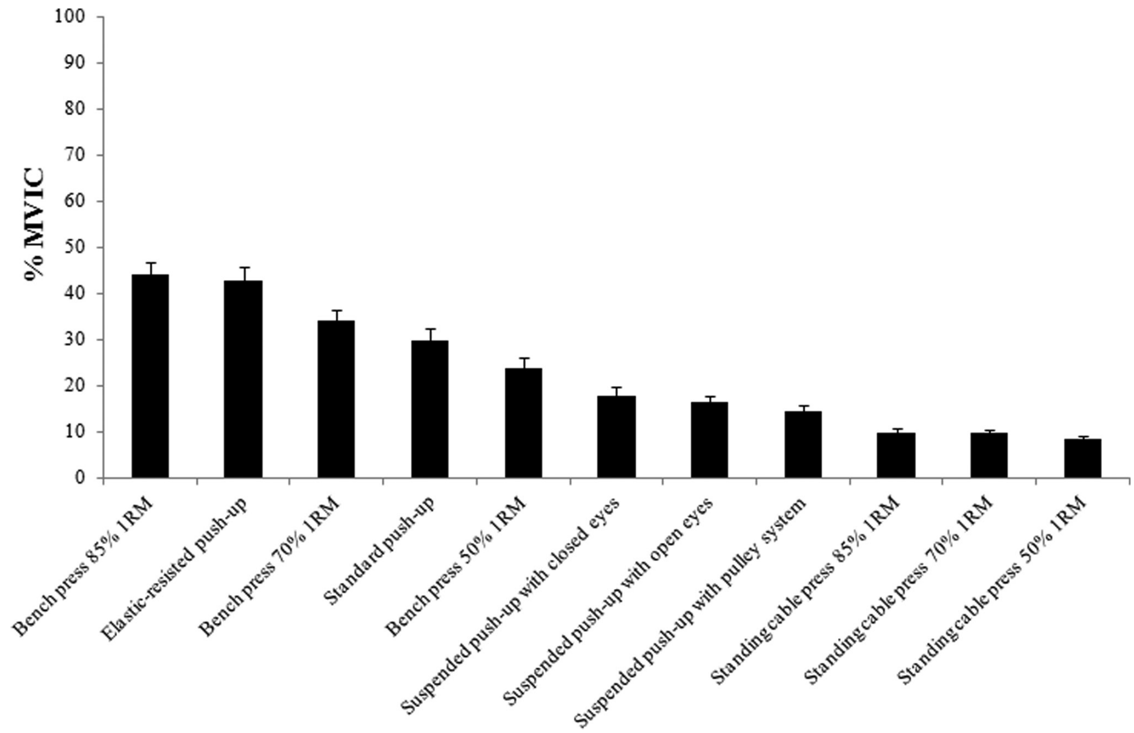
Abbreviation: %MVIC, percentage of maximum voluntary isometric contraction.

Figure 3. Sternocostal head of the pectoralis major normalized mean (± SD) electromyographic signal among exercises.



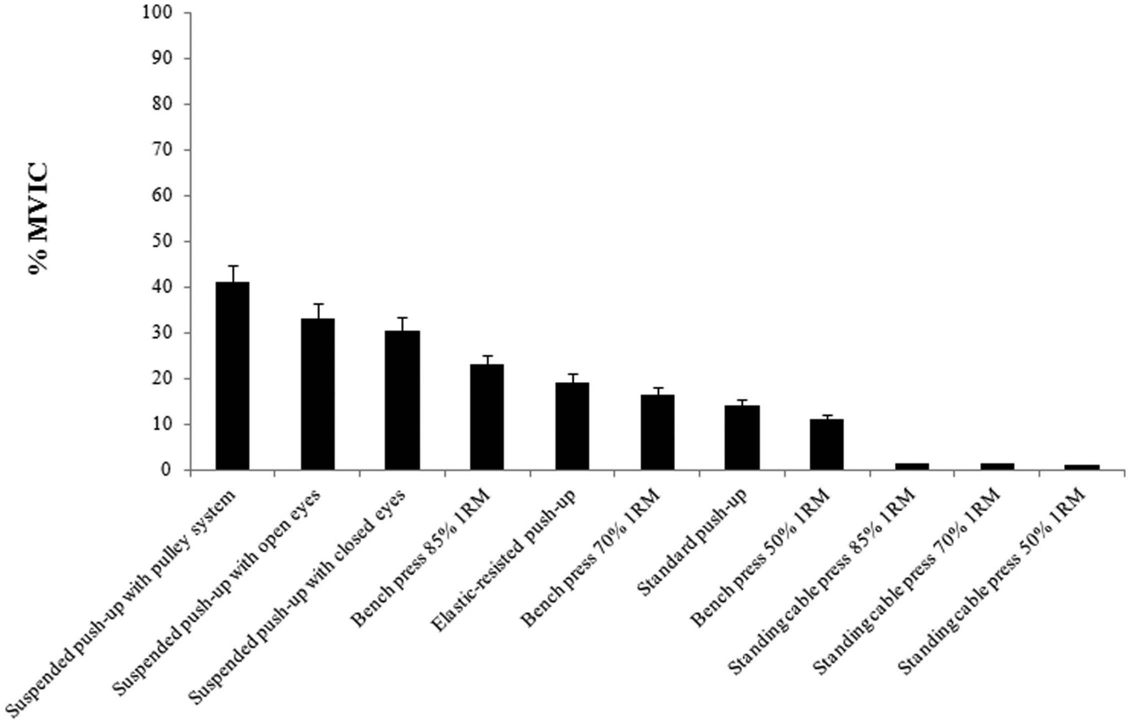
Abbreviation: %MVIC, percentage of maximum voluntary isometric contraction.

Figure 4. Anterior deltoid normalized mean (± SD) electromyographic signal among exercises.



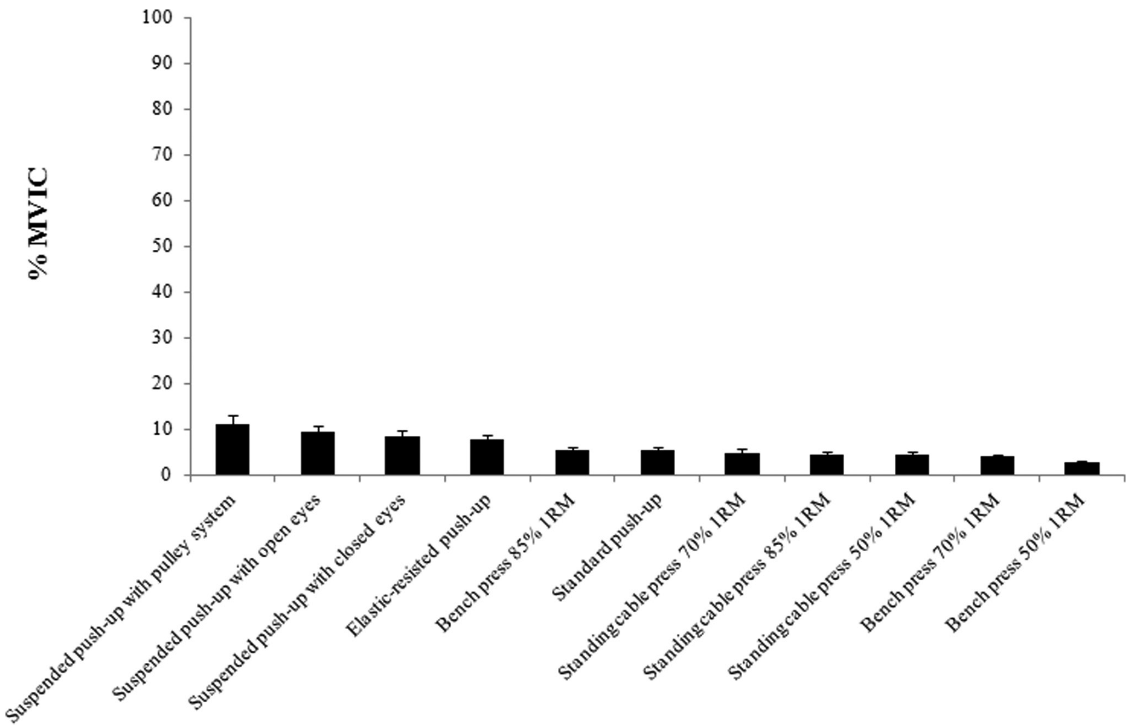
Abbreviation: %MVIC, percentage of maximum voluntary isometric contraction.

Figure 5. Long head of the triceps brachii normalized mean (± SD) electromyographic signal among exercises.



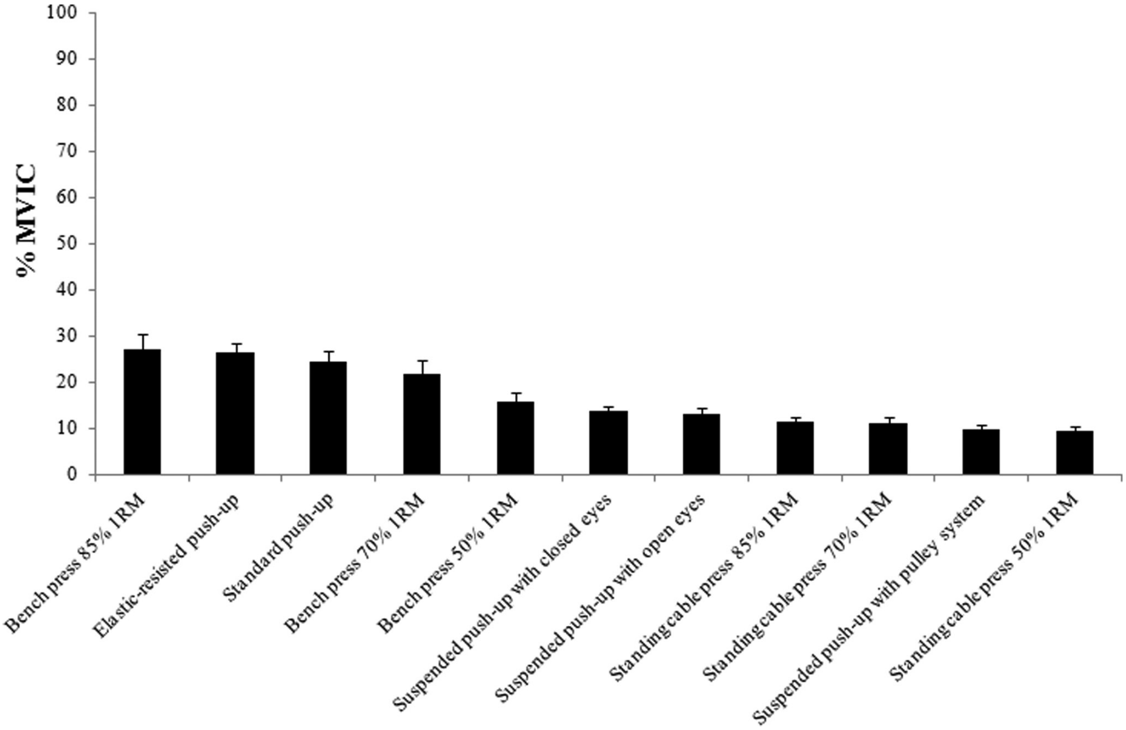
Abbreviation: %MVIC, percentage of maximum voluntary isometric contraction.

Figure 6. Upper trapezius normalized mean (± SD) electromyographic signal among exercises.



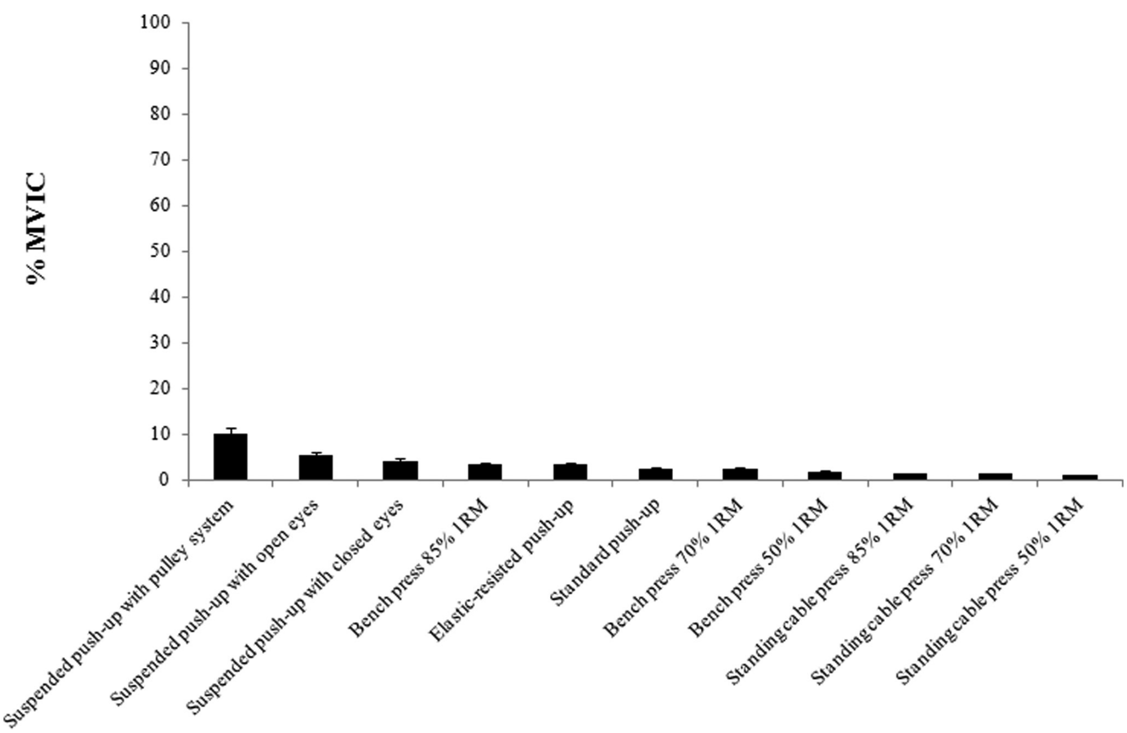
Abbreviation: %MVIC, percentage of maximum voluntary isometric contraction.

Figure 7. Anterior serratus normalized mean (± SD) electromyographic signal among exercises.



Abbreviation: %MVIC, percentage of maximum voluntary isometric contraction.

Figure 8. Posterior deltoid normalized mean (± SD) electromyographic signal among exercises.



Abbreviation: %MVIC, percentage of maximum voluntary isometric contraction.

The suspended condition that was expected to be the most unstable was the only one that provided less PEC activation than the other suspended conditions. This could be explained by excessive postural control requirements during the task.[29] Sensorial manipulation did not enhance PEC activation in comparison with the other suspended conditions, although it was the only one that provided similar PEC activity as the bench press at 70% 1RM. In accordance with Santana et al,[10] the bench press showed higher muscle activation for the prime movers compared with the standing cable press. Notwithstanding, the highest amount of TRICEP activation was achieved with the most unstable suspended condition, possibly due to the difficulty in maintaining the correct technique in spite of the unilateral disruptions and having to perform an adequate elbow extension to complete the exercise. Similarly, it has been reported that there is greater TRICEP activation when instability increased during push-ups.[27,30] On the contrary, TRICEP results suggest that during more stable weight-lifting conditions, a greater load rather than greater instability may be the key point to enhance muscle activation (eg, during the bench press or push-ups with elastic resistance). Previous findings support this notion, reporting a reduction in 6-RM loads during bench press on unstable surfaces that were accompanied by TRICEP activation reduction.[29] Although push-ups have been used to strengthening shoulder musculature,[12] the results suggest that higher unstable conditions may compromise these adaptations. For instance, push-ups on the floor showed greater ADELT activation than suspended push-ups, and additional elastic resistance reaches similar activity levels as the bench press at 70% 1RM and 85% 1RM. An absence of changes in ADELT muscle activation was also reported in unstable/stable push-ups.[26] In contrast, the highest EMG values for the PDELT were found during suspended push-ups, probably because of the increased antagonist co-contraction with unstable conditions,[31] which reduces force output and agonist EMG activity due to reciprocal inhibition.[3,31] In line with Youdas et al,[12] the PDELT was the muscle that showed the least activity levels.

Strength and coordination of the SERRA and TRAPS muscles are of primary interest for shoulder rehabilitation.[32] In accordance with McGill et al,[8] we found that SERRA activation was greater during push-ups on the floor compared with the suspended version. Additionally, higher press stability elicited a higher SERRA activation than the standing counterpart when both were performed at 85% 1RM. Despite suspended push-ups with/without sensorial manipulations showing no TRAPS activation differences between them, one of the eyes-open suspended conditions was the only one that provoked greater TRAPS activation than the bench press at 70% 1RM. In accordance, suspended push-ups showed more than double the %MVIC numerical values for the TRAPS compared with stable push-ups.[8] The SERRA/TRAPS activation ratios have been used to select exercises that maximize SERRA activation while minimizing activation of the TRAPS for optimal shoulder function.[32] The EMG numerical values and the number of statistical differences between conditions suggest that push-ups on the floor and the bench press are the most suitable exercises for this purpose.

It has been assumed that activations below the threshold of 40% to 60% MVIC do not effectively stimulate muscle strength gains.[2] Nevertheless, our PEC results during the bench press at 50% 1RM (ie, 24.63% MVIC) indicate that even lower activation levels may produce strength adaptations. In fact, we found that the bench press performed at very high intensity (ie, 85% 1RM) only produced a PEC activation of 52.91% MVIC in experienced trainees. In addition, due to several variables including an individual's training experience,[5] the EMG normalization technique,[6] or the type of signal analysis that is used, it is difficult to establish a minimally efficient muscle activation threshold and establish comparisons between muscle activation levels across different studies. Therefore, a better approach to associate muscle activation levels with strength adaptations may be a comparison between exercises performed at a certain %RM or RM number instead of only assuming an established threshold that may be less indicative and could lead to misinterpretation of results. Future studies should investigate the relationship between EMG and strength adaptations to improve the practical application of the use of EMG to find optimal exercises. The data provided may not be extrapolated to other populations or to different conditions or muscles.

Conclusion

To our knowledge, this is the first study to characterize the relationship between EMG at different %RM during common upper-body strengthening exercises and different push-up variations. The relationship between EMG activity and %RM in experienced participants shows that strength adaptations may occur with moderate EMG levels.

Elastic-resisted push-ups may induce the same EMG stimulus in the prime movers as the bench press at loads that generally induce hypertrophic adaptations while also providing a greater challenge for the abdominal muscles than the 2 press exercises. The bench press allows for the lifting of greater loads, targets the prime movers, and induces the same stimulus for the abdominal muscles in comparison with the standing cable press. If the aim is to reach high muscle activity levels in the ABS and OBLIQ, the suspended push-up is a highly effective option. Further, closing the eyes and providing greater unilateral disruptions during suspended push-ups are ways to increase the intensity and may increase OBLIQ muscle activation compared with the other conditions. Regarding the PDELT, the highest activation was found during the suspended push-up with the pulley system, although this muscle had low EMG values. The SERRA is highly elicited during more stable conditions, but the TRAPS seems to be affected oppositely. Thus, push-ups and the bench press exercise have the most favorable SERRA/TRAPS activation ratios. Data reported may serve to establish optimal progressions and selection of optimal exercises to develop different resistance training adaptations.

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Conflict of Interest Statement

Joaquin Calatayud, MSc, Sebastien Borreani, PhD, Juan Carlos Colado, PhD, Fernando Martin, PhD, and Michael E. Rogers, PhD, have no conflicts of interest to declare.

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ARTÍCULO III

Calatayud, J., Borreani, S., Colado, J. C., Martin, F., Tella, V., & Andersen, L. L. (2015). Bench press and push-up at comparable levels of muscle activity results in similar strength gains. *Journal of Strength and Conditioning Research, 29*(1), 246–253. http://doi.org/10.1519/JSC.0000000000000589

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Brief running head: Similar muscle activity, similar strength gains.

Manuscript title: **Bench press and push-up at comparable levels of muscle activity results in similar strength gains**

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Conflict of interest

The authors confirm that they do not received financial support for this study, they have no professional relationship with the equipment used during this study and there are no known conflicts of interest associated with this publication that could have influenced its outcome. The results of the present study do not constitute endorsement of the device by the authors or the National Strength & Conditioning Association.

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ABSTRACT

Electromyography (EMG) exercise evaluation is commonly used to measure intensity of muscle contraction. While researchers assume that biomechanically comparable resistance exercises with similar high EMG levels will produce similar strength gains over the long term, no studies have actually corroborated this hypothesis. This study evaluated EMG levels during 6-repetition maximum (6RM) bench press and push-up, and subsequently performed a 5-week training period where subjects were randomly divided into 3 groups (i.e., 6RM Bench press group, 6RM Elastic band push-up group or control group) to evaluate muscle strength gains. Thirty university students with advanced resistance training experience participated in the two-part study. During the training period, exercises were performed using the same loads and variables that were used during the EMG data collection. At baseline, EMG amplitude showed no significant difference between 6RM bench press and band push-up. Significant differences among the groups were found for percent change (Δ) between pre-test and post-test for 6RM ($p=0.017$) and for 1-repetition maximum (1RM) ($p<0.001$). 6RM Bench press group and 6RM Elastic band push-up group improved their 1RM and 6RM (Δ ranging from 13.65 to 22.21) tests significantly with similar gains, whereas Control group remain unchanged. Thus, when the EMG values are comparable and the same conditions are reproduced, the aforementioned exercises can provide similar muscle strength gains.

Keywords: electromyography, bench press, elastic bands, push-up, intensity

INTRODUCTION

The bench press and the push-up are two classic push exercises for strengthening the upper-body (7, 19) also used to asses maximal muscular strength (7) or muscular endurance (2, 20, 24) respectively. In addition, the biomechanical similarities between these exercises have been established several years ago (8). While the bench press usually requires expensive equipment, the push-up can be performed anywhere. The advantage of bench press is the possibility for low, moderate and high training intensities, whereas load during traditional push-up is determined by body weight (8).

Intensity is cardinal in training progressions (19) and high intensities (>80% of 1-repetition maximum [1RM]) are recommended to maximize muscular strength gains in advanced lifters (3). Performing push-ups with bodyweight only is unlikely to provide sufficient training stimulus in advanced trainees. Thus, added resistance may be needed for push-ups to be effective beyond the initial training stage. Due to their low cost, adaptability and portability (26), elastic resistance has become a feasible alternative to traditional resistance training (31). Furthermore, elastic resistance proved effective in inducing comparable EMG levels as those achieved with free weights or training machines during lower body (22, 23, 26) and upper-extremity resistance exercises (1, 4). Hence, added elastic resistance may be sufficient for effective high-intensity push-up training..

Electromyography (EMG) exercise evaluation is frequently used to examine the intensity of muscular activity (27, 4, 5) and consequently estimate the effectiveness of different exercises. Heavy resistance exercise induces relatively high levels of muscle activity (5, 27), which over a training period induce muscle strength gains (27) and may improve athletic performance, musculo-skeletal health and alter body aesthetics (18). Thus, researchers generally assume that exercises with higher EMG levels provide greater muscle strength gains during a training period (5, 6, 16). Indeed, despite the percentage of maximal activity is influenced by several variables (14) it is considered that the level of EMG activation should reach 60% to induce muscle strength and structural adaptation (5). This assumption has been used during years in several papers where exercises with EMG values over this threshold were considered as effective to promote muscle strength adaptations (6, 16, 32, 33). Likewise, biomechanically comparable exercises that yield similar EMG levels are assumed to be equally effective and able of producing similar strength gains (4, 8). However, previous studies have been conducted to analyze either EMG values or to evaluate muscle strength gains after an exercise program rather than integrating both pathways so the effects of applying an exercise with a certain % MVIC in the same subjects is only an assumption. Hence, no studies have evaluated muscle activity during a given exercise and subsequently performed a training program to corroborate these hypotheses. Therefore, the purpose of this study was two-fold: 1) to evaluate the EMG levels during 6-repetition maximum (6RM) bench press and push-up and 2) to evaluate the strength gains after a training period with either the bench press or push-ups with the same loads and variables (i.e., intensity, volume, rest, exercise technique and speed of movement) that were used during the data collection. We hypothesized that the 6RM bench press and the 6RM push-ups would induce similar EMG levels. In addition we hypothesized that these exercises also would lead to similar muscle strength gains after the training program.

METHODS

Experimental approach to the problem

Thirty volunteers participated in a two-part study. In order to examine the first aim of the study and determine the intensity of the exercises as a %MVIC, subjects took part in a repeated measures design assessment. In the first two sessions the subjects were familiarized with the protocol, in the third session they performed a one-repetition maximum bench press test (1RM) and in the fourth session they performed two six-repetition maximum tests (6RM) with EMG data collection. Surface EMG signals were recorded from the muscles: sternocostal head of the pectoralis major (PEC) and anterior deltoid (ADELT). The data obtained were normalized by using the mean root mean square (RMS) values during the maximum voluntary isometric contraction (MVIC) and expressed as a percentage of the maximum EMG. Afterwards, to examine the second aim of the study and determine the effectiveness of the exercises that were previously measured through EMG, subjects took part in a randomized control trial, performing a 5-week training program of either bench press or push-ups with the same loads and variables that were used during the data collection. Finally, the subjects performed 1RM and 6RM bench press tests in separate sessions. The study design attempted to answer the following research question: ‘‘Do two biomechanically comparable exercises – the push-up and bench press – performed at the same relative intensity, as defined by relative EMG amplitude, result in similar strength gains?’’.A visual of the design is presented in Figure 1.

Figure 1 near here

Subjects

Young university students (22 men and 8 women) voluntarily participated in this study. Subject characteristics are presented in Table 1. All subjects had experience using the bench press or the push-up and they had experience in the use of elastic resistance during the push-up exercise since they used this variation in a previous study conducted in the same laboratory. Before beginning with the study they were not involved in a training program using 6RM loads so they were not familiarized with such intensity.

However, participant's training status was considered advanced according to the NSCA classification, since they had a minimum of 1 year of resistance training experience, performing at least 3 sessions per week at moderate/high intensity and they were currently training (7). No significant differences between the training status and the 1RM and 6RM baseline loads were reported among the different groups (see Table 1).

Table 1 about here

None of the participants were taking any medications or anabolic steroids that could influence in the outcomes and none of the participants had musculoskeletal pain, neuromuscular disorders, or any form of joint or bone disease. All participants signed an institutional informed consent form before starting the protocol, and the institutions' review board approved the study. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

Procedures

Each participant took part in 16 sessions in the following order: two familiarization sessions, a 1RM bench press test session, two 6RM tests with EMG data collection, 10 training sessions, a post 1RM bench press estimation session and lastly a post 6RM bench press estimation session. These sessions were performed at the same time during the morning (i.e., between 9 AM and 1 PM), separated by 2 days. The same investigators performed all measurements and the procedures were always conducted in the same facility at 20º C. The study was done during February-March 2013

Several restrictions were imposed on the volunteers before the sessions: no food, drinks or stimulants (e.g. caffeine) to be consumed 3 h before the sessions and no physical activity more intense than daily activities 24 h before the exercises. They were instructed to sleep more than 8 hours the night before data collection.

During the training period, all the subjects were asked to maintain their normal diet and their usual sport practices, avoiding additional activity or changes in the training program that could influence the results so they had to maintain the volume and the training intensity that were using before beginning their participation in the study. In addition, the two intervention groups were asked to refrain from additional training involving the PEC or pushing movements. In addition, they were instructed to consume water ad lib during the exercise performance to ensure hydration (28).

Familiarization Session

During the familiarization sessions, the participants were familiarized with the different exercises, movement amplitude, body position and cadence of movement that would later be used during data collection. Participants practiced the exercises until they felt confident and the researcher was satisfied with their technical execution. Moreover, height (IP0955, Invicta Plastics Limited, Leicester, England), body mass, body fat percentages (Tanita model BF- 350) and biacromial width were obtained according to the protocols used in previous studies (20).

1RM Strength testing sessions

Before the 1RM test, subjects performed mobility drills without ballistic movements to warm up. The testing sessions were separated by two days. The estimation of the 1RM during the bench press in the Smith machine was performed according to the NSCA´s protocol (7). The same bench press technique was used on all test and training sessions. Three to five attempts were used to measure each 1RM in order to avoid fatigue and compromise the accuracy of the test (21). Subjects were positioned supine with the head and trunk supported by the bench, the knees bent, the feet flat on the bench, the elbow flexed 90º and the shoulder abducted 45º. A standardized grip width of biacromial width distance +50% was measured (distance in centimeters between the tips of right and left third digits) and used in every session and condition. At the same time, a researcher was located at the head end of the bench during the test to help in raising the bar on a failed attempt and to help the participant place the bar back on the rack (21). After the 5-week training period, the 1RM test was performed similarly to the pretraining test to examine the strength gains.

6RM Strength testing sessions and EMG data collection

The two pre 6RM estimations and the EMG data collection were performed in the same session. The protocol started with a light warm-up, where each subject performed 5 minutes of mobility drills without ballistic movements. Then, the protocol continued with the preparation of participants' skin, and followed by electrode placement, MVIC collection and exercise performance. Hair was removed with a razor from the skin overlying the muscles of interest, and the skin was then cleaned by rubbing with cotton wool dipped in alcohol for the subsequent electrode placement, positioned according to the recommendations of Cram et al. (14) on the sternocostal head of the pectoralis major (PEC) and anterior deltoid (ADELT), on the dominant side of the body. Pre-gelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S, Medicotest, Olstykke, DNK) were placed with an interelectrode distance of 25 mm. The reference electrode was placed approximately 10 cm from the electrode pair, according to the manufacturer's specifications. Participants then performed 1 standard push-up on the floor in order to check signal saturation. All signals were acquired at a sampling frequency of 1 kHz, amplified and converted from analog to digital. All EMG signals were stored on a hard drive for later analysis. To acquire the surface EMG signals produced during exercise, an ME6000P8 (Mega Electronics, Ltd., Kuopio, Finland) biosignal conditioner was used.

Prior to the test described below, two 5 s MVICs were performed for each muscle and the trial with the highest EMG was selected (4). Participants performed 1 practice trial to ensure that they understood the task. One-minute rest was given between each MVIC and standardized verbal encouragement was provided to motivate all participants to achieve maximal muscle activation. Positions for the MVICs were performed according to standardized procedures, chosen based on commonly used muscle testing positions for the (1) PEC (8, 30) and (2) ADELT (17) and were performed against a fixed immovable resistance (i.e., Smith machine). Specifically: (1) bench press with the previously mentioned technique, (2) shoulder flexion at 90º in a seated position an erect posture with no back support.

At the end of the MVIC´s, subjects rested during 3 minutes and were assigned to the 6RM push-up testing or the 6RM bench press in a counterbalanced order. Both tests were performed separated by 10 minutes of rest and were performed with the aforementioned bench press technique. In addition, a 2:2 ratio (i.e., 2-second rate for descent and 2-second rate for ascent) was maintained by a 30-Hz metronome (Ableton Live 6, Ableton AG, Berlin, Germany) to standardize speed of movement. Visual and verbal feedback was given to the participants in order to maintain the range of movement and hand distance during the data collection. A trial was discarded and repeated if participants were unable to perform the exercise with the correct technique and cadence. If this occurred, the last EMG recording was deleted. The set when the 6RM was achieved was recorded in order to analyze EMG data. The 6RM tests were determined in 3-5 attempts and rest periods between attempts were progressively increased from 1 to 4 minutes according to an established 1RM bench press protocol (7).

For the 6RM bench press testing, three warm-up sets were performed on a stable bench in the Smith machine: 1) 20 repetitions at 25% of the previously estimated 1RM, 2) 10 repetitions at 50% of 1RM and 3) 8 repetitions at 70% of 1RM (7). After these sets, load was estimated and adjusted for the subjects to reach their 6RM. The rationale for using the Smith machine was the absence of muscle activity differences for anterior deltoid and pectoralis major during the free weight bench and the Smith machine bench press, regardless of load or the experience level of the subjects (29).

For the 6RM push-up test, elastic resistance was progressively increased by adding the required number of bands until the subjects were able to perform only 6 reps. Thera-Band elastic band (Hygenic Corporation, Akron,OH,USA) of the colors blue, silver and gold were used and combined to reach the 6RM push-up. The elastic band grip was performed at 0.70 m of the total band length. A research assistant helped the participants placing the band behind their back with the aforementioned length. Then, participants stretched the band to perform the exercise with the proper grip width (i.e., biacromial width distance +50%). During the 6RM push-up testing, participants started the exercise in an extended arm position with forearms and wrists pronated, feet at biacromial (shoulder) width, and fingers flexed. Hip and spine were maintained neutral during all the repetitions. Figure 2 shows the 6RM elastic-resisted push-up.

Figure 2 near here

After testing, subjects were randomly divided into 3 groups (6RM Bench press group, 6RM Elastic band push-up group or control group) and initiated the 5-week training program.

Training period

During the training period all variables were established and controlled to exhaustively mimic the EMG session. Thus, the same Smith machine that was used during the test was also used during the training program by the 6RM Bench press group. The training program had a frequency of 2 sessions per week, conducted on Mondays and Wednesdays with each session lasting approximately 25 minutes. Each session comprised 5 sets of 6 repetitions with the same load/resistance that was used to reach the 6RM during the EMG session and was maintained during all training sessions. Moreover, the same rest, speed of movement, exercise technique and grip width than in the previous sessions were used. Rest between sets was maintained in 4 minutes during all the training period to maintain the required number of repetitions on each set without reductions in the established load/resistance (15). All the training sessions were supervised by a certified strength and conditioning specialist (CSCS) accredited and a research assistant. The control group was instructed to perform their usual tasks during the intervention period.

Data analysis

All surface EMG signal analyses were performed using Matlab 7.0 (Mathworks Inc., Natick, MA, USA). Surface EMG signals related to isometric exercises were analyzed by using the 3 middle seconds of the 5-second isometric contraction. The EMG signals of the dynamic exercises were analyzed by taking the average of the entire six repetitions. All signals were bandpass filtered at a 20- to 400-Hz cutoff frequency with a fourth-order Butterworth filter. Surface EMG amplitude in the time domain was quantified by using RMS and processed every 100 ms. Mean and peak RMS values were selected for every trial and normalized to the maximum EMG (%MVIC). Mean values of the %MVIC of the ADELT and PEC were calculated and analyzed.

Statistical Analyses

Statistical analysis was accomplished using SPSS version 19 (SPSS inc., Chicago, IL, USA). All variables were found to be normally distributed (Shapiro-Wilk's normality test) before data analysis. Results are reported as mean±SE. Statistical comparisons for muscle activation between the conditions were performed using paired sample t-tests. The training-related effects were assessed using repeated measures 2-way ANOVA (factors: group and time). In addition, one-way independent ANOVA was used to assess percent change (Δ) differences among the 3 different groups. Post hoc analysis with Bonferroni correction was used in the case of significant main effects. Significance was accepted when $p \leq 0.05$.

RESULTS

PEC [mean: p=0.927; peak: p=0.968] and DELT [mean: p=0.244; peak: p=0.934] EMG values showed no significant difference between the 6RM bench press and the 6RM push-up. Results are reported in table 2. No significant differences have been found between groups at baseline. In regard of the intervention results there were significant interactions in the 6RM (p=0.007) and 1RM (p<0.001) tests. Significant differences among the groups have been found for percent change (Δ) for 6 RM (p=0.017) and for 1 RM (p<0.001). 6RM Bench press group and 6RM Elastic band push-up group improved their 1RM and 6RM tests significantly with similar gains, whereas Control group remain unchanged. Results are reported in table 3 and table 4.

Table 2 about here

Table 3 about here

Table 4 about here

DISCUSSION

This is the first study combining EMG exercise evaluation with a subsequent training period to compare strength gains between two different resistance exercises performed with similar intensity, volume, rest, exercise technique and speed of movement. Our study shows that push-ups with added elastic resistance induces similar high levels of muscle activity and strength gains as the more popular Smith machine bench press.

In our study, the 6RM bench press and the 6RM push-up induced equally activation for the PEC and DELT. In line with this, elastic resistance and dumbbells showed comparable levels of muscle activation during several assistance exercises that target neck, shoulder, forearm (4), biceps brachii (1) and quadriceps (26) muscles. A relationship between similar muscle activation and similar muscle strength adaptations has been assumed for years in EMG studies (4, 8), although their verification through a resistance training intervention remained uninvestigated. Thus, the main finding in our study was that the comparable levels of muscle activation during both exercises also were transformed in comparable muscle strength gains after a short-term resistance program. In addition, since EMG levels below the threshold of 60%MVIC has been considered ineffective to produce strength adaptations (5), another relevant and novel finding in our study is that lower EMG values (i.e., 52%MVIC) induced a high intensity stimulus, which were adequate to produce muscle strength gains.

In line with our findings, Kraemer et al. (25) found that elastic bands were capable of providing a heavy resistance stimulus during a training program. In the same vein, some studies were conducted to compare adaptations between elastic vs. other resistance training methods. For instance, short-term training program showed the efficacy of elastic resistance to produce comparable strength adaptations to those obtained from weight machines among sedentary middle-aged woman (11). A resistance training program using elastic resistance or weight machines and free weights demonstrated also equivalent isometric force improvements among fit young women (10). Moreover, Colado et al. (12) found comparable improvements in body composition, physical fitness and blood chemistry after 24 weeks in which middle-aged women were involved in elastic resistance training program or a water-based strength training program. In this regard, we found that the elastic-resisted push-up group and the bench press group improved their 6RM bench press test and their 1RM bench press test to a similar extent.

Our results show that biomechanically comparable exercises yield similar EMG levels and muscle strength gains when they are performed under the same conditions, i.e. intensity, volume, rest, exercise technique and speed of movement. Greater strength improvements could be expected due to a possible greater training transference in the bench press group since they were tested and trained in the same exercise and the same Smith machine. In addition, there are some differences between the exercises that could have influenced the results. For example, the performance of the bench press in the Smith machine provides a stable condition (29) and allows a less natural weight lifting than non-guided variations (13). However, our results suggest that these differences between the exercises seem to have less importance than the biomechanical similarities. Indeed,despite strength improvements are dependent of the specific exercise that is performed (18), the biomechanical similarities during the both exercises that were performed in our study (8) could explain the muscle strength transference that was achieved during the bench press test after an elastic-resisted push-up training program.

A previous study failed to report improvements in the 1RM bench press and the push-up endurance muscular test after a push-up training program (9). Nevertheless, in that study the training intensity may not have been high enough to produce strength adaptations in advanced lifters. Our study demonstrated that the push-up may reach an adequate intensity to induce muscle strength adaptations with the use of additional elastic resistance in advanced participants.

The data provided may not be extrapolated to other populations, other exercise involving different conditions or muscles. Furthermore, the use of a periodization fashion could lead to different results, despite we considered that for our purpose, the performance of the same variables during al the training program was needed in order to mimic the EMG test session. Additionally, it should be taken into account that the %MVIC is influenced by several variables like the normalization technique that is used for the MVIC´s (14, 17) and thus it is difficult to use a concrete muscle activation threshold and establish comparisons between muscle activation levels across different studies.

The 5 weeks of training were sufficient to induce strength improvements likely due to neurological adaptations (3, 18). Nevertheless, Future studies should compare the effectiveness of the 2 training methods, especially in longer training programs and should investigate the relationship between EMG and strength adaptations to improve the practical application of the EMG studies. However, to our knowledge, this is the first study aiming to estimate the muscle strength adaptations by integrating and applying the EMG measurements with a subsequent training program. Importantly, our study validates the use of EMG to select effective resistance exercises to promote strength gains in trained individuals.

PRACTICAL APPLICATIONS

Elastic-resisted push-ups induce similar muscle activations levels and strength gains as the bench press when these exercises are performed under the same conditions (i.e., intensity, volume, rest, exercise technique and speed of movement). Hence, when the same conditions are reproduced and the aforementioned exercises reach the required intensity, comparable EMG values result in comparable muscle strength gains.

The push-up exercise with added elastic resistance provide a feasible and cost-effective option that may be performed anywhere and may be used as an alternative to traditional bench press exercise in order to provide a high intensity stimulus in the prime movers involved in the action and produce maximal strength adaptations. Physical therapists and Strength and conditioning specialists may use this information to select or include one of the both exercises performed during a resistance training program. Practitioners must be aware that even EMG values below 60%MVIC can produce a high intensity stimulus and the assumption of this threshold could lead to under/overestimate the results and thus provide wrong conclusions. This data provides information that may have direct implications in athletic performance and musculo-skeletal health and contributes to improve the criterion to select optimal exercises when only EMG data is available.

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endorsement of the device by the authors or the National Strength & Conditioning Association.

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Figure caption

Fig 1. Study scheme.

Figure caption

Fig 2. 6RM elastic-resisted push-up test.

Table 1. Subjects characteristics

	N	Gender	Age (years)	Height (cm)	Weight (kg)	Body fat (%)	Biacromial distance	Strength experience (years)
Control	10	M = 7 F = 3	21.9 (2.1)	171.6 (7.6)	67.5 (6.3)	13.9 (6.5)	41.2 (3.0)	1.9 (1.9)
Elastic Band	10	M = 8 F = 2	20.6 (1.7)	175.4 (6.8)	74.7 (8.0)	13.9 (5.9)	43.2 (2.6)	1.9 (2.9)
Bench Press	10	M = 7 F = 3	22.7 (3.3)	173.1 (7.0)	67.7 (8.8)	13.6 (6.1)	42.4 (3.5)	2.4 (2.8)
Total	30	M = 22 F = 8	21.9 (2.4)	172.8 (7.6)	70.6 (8.9)	14.0 (5.8)	42.2 (3.1)	2.1 (2.4)

M=male; F=female. Data are expressed as mean (SD).

Table 2. Mean and peak muscle activation between conditions (n=30)

	Mean %MVIC		Peak %MVIC	
	PEC	DELT	PEC	DELT
Elastic Bands	52.90 (2.55)	62.32 (2.87)	139.73 (6.87)	139.69 (6.10)
Bench Press	52.70 (1.85)	59.53 (3.54)	139.98 (6.66)	139.28 (7.70)

PEC = sternocostal head of the pectoralis major; DELT = anterior deltoid. Data are expressed as a mean (SEM) in percentage of the maximum voluntary isometric contractions (MVIC).

Table 3. Bench press 6RM (kg) at baseline and after 5 weeks.

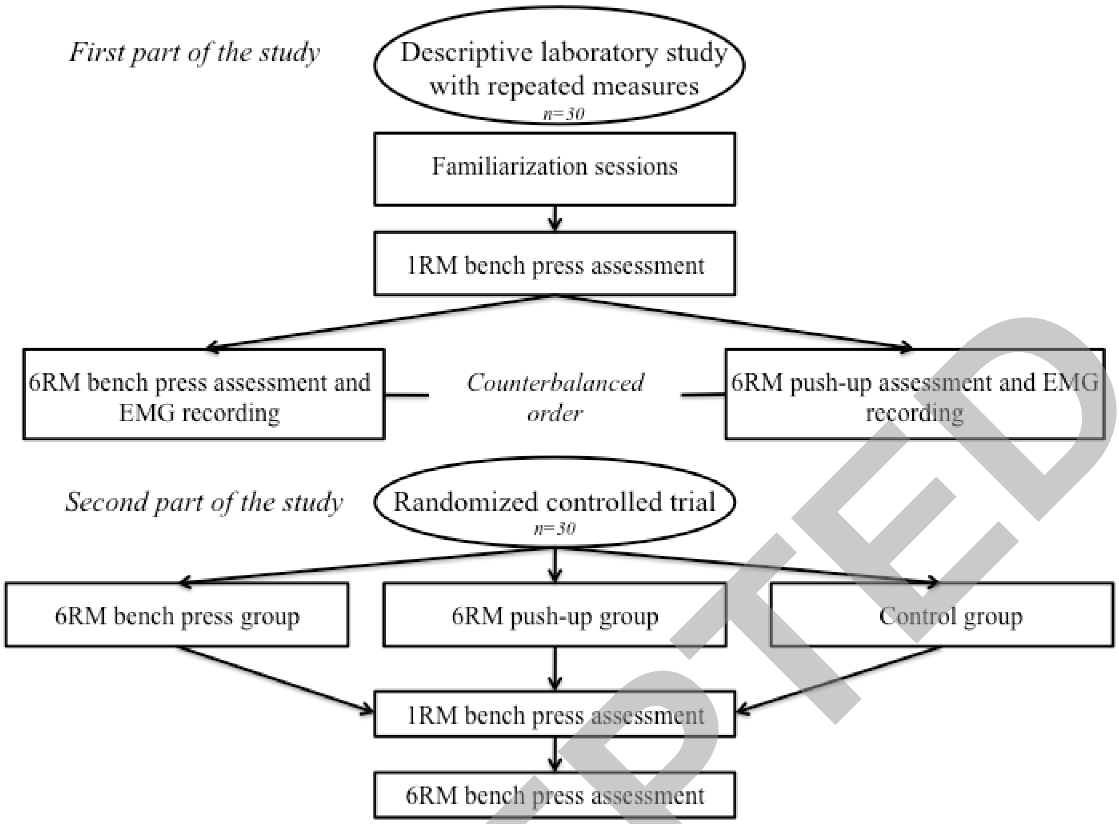
	Pre-test	Post-test	Δ (%)	p	p interaction
Control	52.51 (20.49)	53.59 (19.87)	2.72 (0.08)	0.344	
Elastic Band	53.20 (13.59)	62.57 (11.51) †	21.04* (0.22)	<0.001	0.007
Bench Press	57.70 (18.45)	69.95 (21.07) †	22.21* (0.13)	<0.001	

* Different ($p \leq 0.05$) from Control Group
†Significant difference to baseline.
Data are expressed as mean (SD).

Table 4. Bench press 1RM (kg) at baseline and after 5 weeks.

	Pre-test	Post-test	Δ (%)	p	p interaction
Control	64.45 (26.82)	65.57 (27.48)	1.68 (0.02)	0.497	
Elastic Band	66.75 (13.71)	75.33 (13.98) †	13.65* (0.14)	<0.001	< 0.001
Bench Press	70.64 (20.05)	83.70 (23.57) †	19.84* (0.20)	<0.001	

* Different (p≤0.05) from Control Group
†Significant difference to baseline.
Data are expressed as mean (SD).


First part of the study
Descriptive laboratory study with repeated measures
n=30
Familiarization sessions
1RM bench press assessment
6RM bench press assessment and EMG recording
Counterbalanced order
6RM push-up assessment and EMG recording
Second part of the study
Randomized controlled trial
n=30
6RM bench press group
6RM push-up group
Control group
1RM bench press assessment
6RM bench press assessment

ARTÍCULO IV

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("The following article is a non-final version. The final publication is available at http://link.springer.com/article/10.1007%2Fs00421-015-3305-7").

Importance of mind-muscle connection during progressive resistance training

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Abbreviation list

electromyography= EMG

pectoralis major = pectoralis

tricepsbrachii = triceps

one-maximum repetition = 1RM

root-mean-square = RMS

Abstract

Purpose This study evaluates whether focusing on using specific muscles during bench press can selectively activate these muscles.

Methods Altogether 18 resistance-trained men participated. Subjects were familiarized with the procedure and performed one-maximum repetition (1RM) test during the first session. In the second session, 3 different bench press conditions were performed with intensities of 20, 40, 50, 60 and 80 % of the pre-determined 1RM: regular bench press, and bench press focusing on selectively using the pectoralis major and triceps brachii, respectively. Surface electromyography (EMG) signals were recorded for the triceps brachii and pectoralis major muscles. Subsequently, peak EMG of the filtered signals were normalized to maximum maximorum EMG of each muscle.

Results In both muscles, focusing on using the respective muscles increased muscle activity at relative loads between 20 and 60 %, but not at 80 % of 1RM. Overall, a threshold between 60 and 80 % rather than a linear decrease in selective activation with increasing intensity appeared to exist. The increased activity did not occur at the expense of decreased activity of the other muscle, e.g. when focusing on activating the triceps muscle the activity of the pectoralis muscle did not decrease. On the contrary, focusing on using the triceps muscle also increased pectoralis EMG at 50 and 60 % of 1RM.

Conclusion Resistance-trained individuals can increase triceps brachii or pectarilis major muscle activity during the bench press when focusing on using the specific muscle at intensities up to 60 % of 1RM. A threshold between 60 and 80 % appeared to exist.

Key Words: Muscle activation, internal focus, strength training, bodybuilding

Introduction

For years bodybuilders have used the principle of focusing on contracting specific muscles to enhance muscle size and increase 'the pump'. Indeed, the American College of Sports Medicine considers the technique of voluntarily squeezing the muscles as a way to provide self-resistance during resistance training (Ratamess 2011). However, scientific literature evaluating the effectiveness of selectively focusing on specific muscles during exercise performance is scarce (Snyder and Fry 2012). Different verbal instructions have provided greater EMG response during maximal isometric contractions of both the elbow flexors and leg muscles (Sahaly et al. 2003). Instructions to selectively activate specific muscles also yielded greater core muscle activity compared with non-instructed conditions during a squat performed at 50% of the one-maximum repetition (1RM) (Bressel et al. 2009). Similar results have been observed for low-intensity exercises such as trunk curls (Karst and Willett 2004) and the abdominal hollowing exercise (Critchley 2002).

In a recent study, untrained individuals were able to selectively increase the activity of the latissimus dorsi muscle during a pull-down exercise performed at 30% of maximal force compared to the normal condition (Snyder and Leech 2009). In addition, Snyder and Fry (2012) found that male Division III football players selectively increased the muscle activity of the prime movers during bench press performed at 50% of 1RM, following verbal instructions to focus on activating either the pectoralis major or triceps brachii. However, verbal instructions performed at the highest intensity (80%1RM) did not consistently lead to increased muscle activity (Snyder and Fry 2012). While the aforementioned study only used two different intensities, a wide range of intensity levels are required to understand the potential dose-response relationship between verbal instructions and specific muscle activation.

Based on the aforementioned studies, voluntarily focusing on specific muscles to increase muscle activity may be possible at low to moderate intensities, whereas the voluntary recruitment of muscles may be more difficult at high intensities. Nevertheless, the dose-response relationship between intensity and the ability to selectively activate specific muscles remains unknown. Higher levels of EMG activity during resistance training in general lead to greater muscular strength adaptations in both rehabilitation and condition programs by providing additional neural drive to the muscle and increased local muscle fatigue (Andersen et al. 2006; Folland and Williams 2007). Hence, the possibility of selectively increasing muscle activity during certain exercises without increasing the external load could serve potential benefits both during rehabilitation and conditioning programs.

Thus, the aim of the present study was to evaluate whether focusing on using the pectoralis major and triceps brachii muscles, respectively, during bench press can selectively increase activity of these muscles. Especially, we were interested in measuring the relationship between exercise intensity and the magnitude of selective activation. We expected that the ability to selectively activate these muscles would decrease with increasing intensity in a dose–response fashion.

Methods

Participants

A total of 18 young male subjects voluntarily participated in the study. Participants' were considered recreationally trained since they had a minimum of 1 year of resistance training experience, performing at least 3 sessions per week at moderate-to-high intensity. In addition, they were familiarized with the bench press exercise. Exclusion criteria were blood pressure above 160/100, disc prolapse, or serious chronic disease. All participants were informed about the purpose and content of the investigation. Informed consent was obtained from all individual participants included in the study. The study conformed to The Declaration of Helsinki and was approved by the Local Ethical Committee (H-3-2010-062).

Experimental procedures

Each participant took part in 2 sessions: A 1RM bench press determination with familiarization session and 1 experimental session. A minimum of 2 days separated the sessions. Participants received instructions to avoid physical activity more intense than normal daily activities 24 h before the sessions. To control the influence of external factors possibly affecting bench press performance, all measurements were made by the same two investigators and were conducted in the same facility. Only the two investigators and the particular subject were at the facility at the same time during the measurements. The study was done during April-May 2014.

At the 1RM bench press determination and familiarization session, height (Seca model 217, Hamburg, Germany), body mass, body fat percentages (Tanita model MC-180MA, Tokyo, Japan) and biacromial width were obtained. Before the 1RM determination, the participants performed mobility drills without ballistic movements to warm up. The 1RM test was performed with the same technique and body position that would later be used during data collection. The measurement of the 1RM for the bench press was performed according to the protocol described by the National Strength and Conditioning Association (Baechle and Earle 2008). At the same time, a researcher was located at the head end of the bench during the test to assist in raising the bar on a failed attempt and to help the participant place the bar back on the rack. Assessment of 1RM enabled calculation of the precise training loads used in the bench press during the following experimental session (20, 40, 50, 60 and 80 % of 1RM). After the 1RM determination, the participants were familiarized with the different conditions, movement amplitude, body position, and speed of movement that would later be used during data collection. Participants practiced the exercise at 50% of 1RM, at least 3 times for each condition, until the participant felt confident and the researchers were satisfied that the correct technique had been achieved.

The experimental session protocol started with the preparation of participants' skin, followed by electrode placement and exercise performance. Hair was removed with a razor from the skin overlying the muscles of interest, and the skin was then cleaned by rubbing with cotton wool dipped in scrubbing gel (Acqua gel, Meditec, Parma, Italy), to reduce impedance (Jakobsen et al. 2013). Afterwards, electrodes were placed according to recommendations of Criswell and Cram (Criswell and Cram 2011) on the following muscles: the lateral head of the triceps, long head of the triceps, clavicular portion of the pectoralis major and sternocostal portion of the pectoralis major. Additional electrodes were placed two cm apart from the sternum in the clavicular portion of the pectoralis major and two cm apart from the sternum the sternocostal portion of the pectoralis major. In addition, electrodes were placed on the muscle belly of the medial triceps brachii portion. Pre-gelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S, Medicotest, Olstykke, Denmark) were placed with an interelectrode distance of 2 cm. The reference electrode was placed approximately 10 cm away from each muscle, according to the manufacturer's specifications. Once the electrodes were placed, participants performed one standard push-up on the floor in order to check signal saturation and quality. All signals were acquired at a sampling frequency of 1500 Hz, amplified and converted from analog to digital. All records of myoelectrical activity (in microvolts) were stored on a hard drive for later analysis.

The participants started all the bench press trials in an extended arm position with forearms and wrists pronate and feet at biacromial (shoulder) width. In the flexed position, the forearm and wrists were kept pronated, whereas the elbow was flexed until the bar touched the chest and the shoulder was abducted to approximately 45º. The hips and spine were maintained neutral during all repetitions. If exercise technique did not meet required expectations the set was discarded and another attempt was made after explaining the procedure to the subject. Elbow joint angle was continuously measured using an electronic inclinometer (2D DTS inclination sensor, Noraxon, Arizona, USA) placed at the lateral side of the humerus. The inclinometer data was synchronously sampled with the EMG data, using the 16-channel 16-bit PC-interface receiver (TeleMyo DTS Telemetry, Noraxon, Arizona, USA). The dimension of the probes was 3.4 cm x 2.4 cm x 3.5 cm. During subsequent analysis, the inclinometer signals were digitally lowpass filtered using a 4th order zero-lag Butterworth filter (3 Hz cutoff frequency). The concentric and eccentric phases were defined as periods with negative or positive angular velocity, respectively, (going from 90º-0º or 0º-90º, respectively).

Participants performed the following conditions, randomly assigned: bench press at 20, 40, 50, 60 and 80 % of the 1RM. Furthermore, participants performed 3 different conditions performed in a randomized order with each of the aforementioned exercises and intensities: regular bench press as described above, and bench press focusing on selectively using the pectoralis major and triceps brachii, respectively. The pectoralis major instruction was as follows: "during this set, try to focus on using your chest muscles only". The triceps brachii instruction was as follows: "during this set, try focus on using your triceps muscles only". The researcher made sure to show by palpation where these muscles were located on the subject to avoid misunderstandings. In the regular bench press condition the instruction was as follows: "during this set, lift the barbell in a regular way". A 1-min rest interval was given between all the conditions except during the 80 % of the 1RM condition, where 3-min rest interval was provided to avoid any influence from fatigue. Each participant performed only three consecutive repetitions in all conditions and with all relative loads to avoid the influence of fatigue on the subsequent condition (Jakobsen et al. 2013). Subjects were instructed and practiced during the familiarization trial how to maintain a pace of 2-second descent and 2-second ascent. The speed of movement was closely monitored by the researcher using the EMG software, and feedback was provided to correct the subjects if any variance was noted. Using tape as marker on the barbell, standardized grip widths of biacromial width distance +50 % (distance in centimeters between the tips of right and left third digits) was maintained during all the conditions. A trial was discarded and repeated if participants were unable to perform the exercise with the correct technique or if a subject stated that he had forgotten the instruction.

Data analysis

During later analysis all raw EMG signals obtained during the exercises were digitally filtered, consisting of 1) high-pass filtering at 10 Hz, and 2) a moving root-mean-square (RMS) filter of 500 ms. For each individual muscle, peak RMS EMG of the 3 repetitions performed at each level was determined, and the average value of these 3 repetitions was then normalized to the maximal RMS EMG obtained during the experimental session (maximal maximorum EMG of each muscle). Normalized values for each muscle were averaged for the 4 different portions at the pectoralis muscle (pectoralis) and the 3 different portions at the triceps brachii muscle (triceps).

Statistical Analyses

A two-way repeated measures linear mixed model (Proc Mixed, SAS version 9, SAS Institute, Cary, NC) was used to determine if differences existed between condition (regular bench press, pectoralis focus, triceps focus) and relative intensity (20, 40, 50, 60, 80% of 1RM) for the pectoralis and triceps muscles separately. Normalized EMG was the dependent variable. Subject was entered in the model as a random factor. Values are reported as least square means (SE) unless otherwise stated. P-values <0.05 were considered statistically significant.

Results

Table 1 shows that the 18 men of the present study had 8 (SD 6) years of resistance training experience, with a 1RM bench press of 103 (SD 25) kg.

Table 2 as well as Figs. 1 and 2 show the normalized EMG values of the pectoralis and triceps muscles, respectively, during the three conditions, i.e. regular bench press, and bench press focusing on using the pectoralis and triceps muscles, respectively. The normalized EMG values agreed well with the relative load, e.g. during regular bench press at 50 % of 1RM the normalized EMG of the pectoralis and triceps were 52 and 55 %, respectively. For both the pectoralis and triceps muscles, focusing on using the respective muscles increased muscle activity at relative loads between 20% to 60% of 1RM, but not at 80% of 1RM. There was no strong indications that the ability to selectively increase activity decreased in a dose-response fashion, but rather that a threshold between 60% and 80% existed. The increased activity did not occur at the expense of decreased activity of the other muscle, e.g. when focusing on using the triceps muscle, the activity of the pectoralis muscle did not decrease. On the contrary, focusing on using the triceps muscle also slightly increased pectoralis EMG at 50% and 60% of 1RM.

Table 1 about here

Table 2 about here

Figure 1 about here

Figure 2 about here

Discussion

The study shows that experienced participants can selectively activate pectoralis and triceps muscles during the bench press when this exercise is performed at low to moderate intensities. Specifically, a selective activation was possible at loads between 20% and 60%, but not at 80% of 1RM.

In contrast to our initial expectations, we found no strong indications that the ability to selectively increase activity decreased in a dose–response fashion, but rather that a threshold between 60 and 80 % existed. Thus, only for the triceps at 20 % was the selective activation higher than the other intensities. For the remainder intensities below 80 % the selective activation ranged between 5 to 9 %.

Our results are in line with the findings reported by Snyder and Fry (Snyder and Fry 2012), -although they used only two intensities- who found that a group of footballers with at least 6 months of experience with the exercise were able to selectively increase muscle activity in pectoralis and triceps muscles during the bench press performed at 50 % of 1RM after the respective verbal instructions. However, in contrast to our findings, Snyder and Fry (2012) found that instruction to use pectoralis muscles during the 80% of 1RM increased pectoralis and anterior deltoid muscle activity while triceps remained unchanged. Even though we used experienced participants, it seems that the effort required by the prime movers to lift heavy weights (i.e 80% of 1RM) makes selective activation of muscles difficult, probably because of the greater force production and motor unit recruitment required to lift heavy weights. The values of the firing rates and recruitment thresholds of motor units vary among muscles and can occur below 100 % of MVIC (De Luca and Kline 2012). However, the three submaximal-maximal repetitions performed with each condition may not have been enough to reach a maximum threshold of motor unit recruitment even though the EMG signal progressively increased through the different conditions for both muscles (see Figs. 1, 2). It is plausible that subjects are mainly and involuntarily focused on lifting the weight when high intensities are reached. It may thus be more difficult to dissociate between the naturally required and the selective or voluntary activation. Indeed, the majority of studies that reported greater muscle activity after specific instructions in dynamic movements used body weight as resistance (Critchley 2002; Karst and Willett 2004) or loads ranging from 30 to 50 % of the maximal intensity (Snyder and Leech 2009; Bressel et al. 2009).

A surprising finding was that concurrent muscle activity of the pectoralis also increased for when focusing on the triceps at moderate intensities. When the participants focused on using the triceps only, a slightly increased pectoralis activity at 50 and 60 % of 1RM was observed. However, when participants were focused on using the pectoralis, the activity of the triceps remained unchanged during all the intensities. While results provided by Snyder and Fry (Snyder and Fry 2012) did not report relaxation of the concurrent muscle during specific instructions in the bench press exercise, other authors showed that it is possible to voluntarily decrease muscle activity in some situations at low contraction intensity (Karst and Willett 2004). For instance, following instruction participants were able to increase external and internal oblique activity while concurrently decreasing rectus abdominis activity during the trunk curl exercise (Karst and Willett 2004). However, the contrary case was not possible, probably because of the dominant role of the rectus abdominal muscle during this exercise (Karst and Willett 2004). In the same vein, another study found that participants using only the load of the arm as resistance at different shoulder joint positions were able to decrease EMG after concrete instructions to reduce upper trapezius activity together with the use of EMG biofeedback, while activity of the transverse trapezius muscle and rhomboids major and minor increased (Palmerud et al. 1998). Thus, the majority of these studies used relatively low levels of resistance that may have limited practical value.

A primary reason explaining our findings could be found in the "*constrained action hypothesis"* described by Wulf et al. (2001), which explains the comparative benefits of adopting an external (i.e., when the attention is focused on the effect of the action or outcome) or internal focus of attention (i.e., when the attention is just focused on the action or movement as in our study). According to this theory, less muscle activity would be induced by the external rather than internal focus due to a greater coherence between sensory input and motor output (McNevin and Wulf 2002). Thus, only the minimum required amount of motor units would be recruited to produce a certain movement (Vance et al. 2004). The use of different focus of attention during an action has been investigated during the last years during different sport skills in field-like conditions (Wulf et al. 1999) and during typical resistance training movements (Vance et al. 2004; Marchant et al. 2009; Greig and Marchant 2014). For example, Vance et al. (2004) found that the neuromuscular activity in the biceps brachii during the biceps curl exercise was generally lower during the external focus condition, where the participants were focused on the movement of the bar instead of the muscle and arm movements (internal focus). More recently, Marchant et al. (2009) found that the external focus during isokinetic elbow flexions decreased peak and mean biceps brachii EMG values in comparison to internal condition. Similarly, Greig and Marchant (2014) reported that an external focus significantly decreased biceps brachii activity at all speeds when compared to an internal focus during an isokinetic elbow flexion. Since the verbal instructions provided in our study supposes the use of an internal focus, our results are in line with the previously mentioned literature.

Our study has both strengths and limitations. A limitation is that we did not measure antagonist muscle activity as in the study by Snyder and Fry. Furthermore, this study was conducted in a group of recreationally trained participants and results may not be extrapolated to other populations or different exercises and muscles. The EMG amplitude reflects a combination of motor unit recruitment, firing rates and degree of motor unit synchronization (Aagaard 2003). Thus, we cannot know whether EMG increases in our study were due to increases in firing rates or in motor unit recruitment. Increased motor unit synchronization occurs mainly during fatiguing muscle contractions and is therefore unlikely to influence the present findings using only three repetitions per set. Despite EMG cross-talk may be present, we consider that the use of an averaged value for the different portions of the pectoralis major and triceps brachii is a strength of our study, providing more representative EMG values for the entire muscle. This is especially relevant in the present study, where participants were to focus on the entire muscle and not a certain portion.

Conclusions

Experienced participants can increase muscle activity at low and moderate intensities without increasing external load after receiving instructions to focus on activating specific muscles during the bench press exercise. Verbal instruction not only increases muscle activity without subsequent decreases in the concurrent muscle activity, but also may provide additional activity to some extent of the concurrent muscle. The practical application is that intensity of muscle activity can be increased to some extent simply by focusing on using that muscle without increasing external load.

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Conflicts of interest

No conflicts of interest or sources of funding are declared by the authors of this article.

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Table 1. Demographics and resistance training variables (n=18, all men)

	Mean (SD)
Age (years)	31 (8)
Height (cm)	179 (8)
Body weight (kg)	82 (10)
Body fat percentage	15 (5)
BMI ($kg \cdot m^{-2}$)	26 (3)
Resistance training experience (years)	8 (6)
1 RM Bench Press (kg)	103 (25)

Table 2. Normalized EMG of the pectoralis and triceps muscles, respectively, during regular bench press and bench press with focus on using the pectoralis and triceps muscles, respectively. Between-condition differences and P-values are provided in the last columns.

	% 1 RM	Regular Bench Press	Focus pectoralis	Focus triceps	Δ Focus pectoralis - Regular	P	Δ Focus triceps - Regular	P
Pectoralis EMG	20	21 (16 - 25)	28 (23 - 32)	20 (15 - 24)	7 (3 - 10)	<.0001	-1 (-4 - 3)	0.6288
	40	38 (34 - 43)	44 (39 - 48)	40 (35 - 44)	5 (2 - 9)	0.0037	1 (-2 - 5)	0.3973
	50	52 (47 - 56)	57 (53 - 62)	55 (51 - 60)	6 (2 - 9)	0.0018	4 (0 - 7)	0.0383
	60	56 (52 - 61)	65 (61 - 70)	61 (57 - 66)	9 (5 - 12)	<.0001	5 (1 - 8)	0.0072
	80	81 (77 - 86)	80 (75 - 84)	82 (77 - 87)	-1 (-5 - 2)	0.4888	1 (-3 - 4)	0.6082
Triceps EMG	20	31 (26 - 36)	32 (27 - 36)	42 (37 - 47)	1 (-3 - 4)	0.6141	11 (8 - 15)	<.0001
	40	47 (42 - 52)	46 (41 - 50)	53 (48 - 58)	-1 (-5 - 2)	0.499	6 (3 - 10)	0.0004
	50	55 (50 - 60)	54 (49 - 59)	59 (54 - 64)	-1 (-4 - 3)	0.6002	4 (0 - 7)	0.0296
	60	60 (55 - 65)	59 (54 - 64)	64 (60 - 69)	-1 (-4 - 3)	0.7365	5 (1 - 8)	0.0082
	80	80 (75 - 85)	81 (76 - 85)	82 (78 - 87)	1 (-3 - 4)	0.7031	3 (1 - 6)	0.1408

Fig. 1 Illustration of the dose–response relationship between intensity (% of 1RM) and muscle activity (normalized EMG) for the pectoralis during the three different conditions

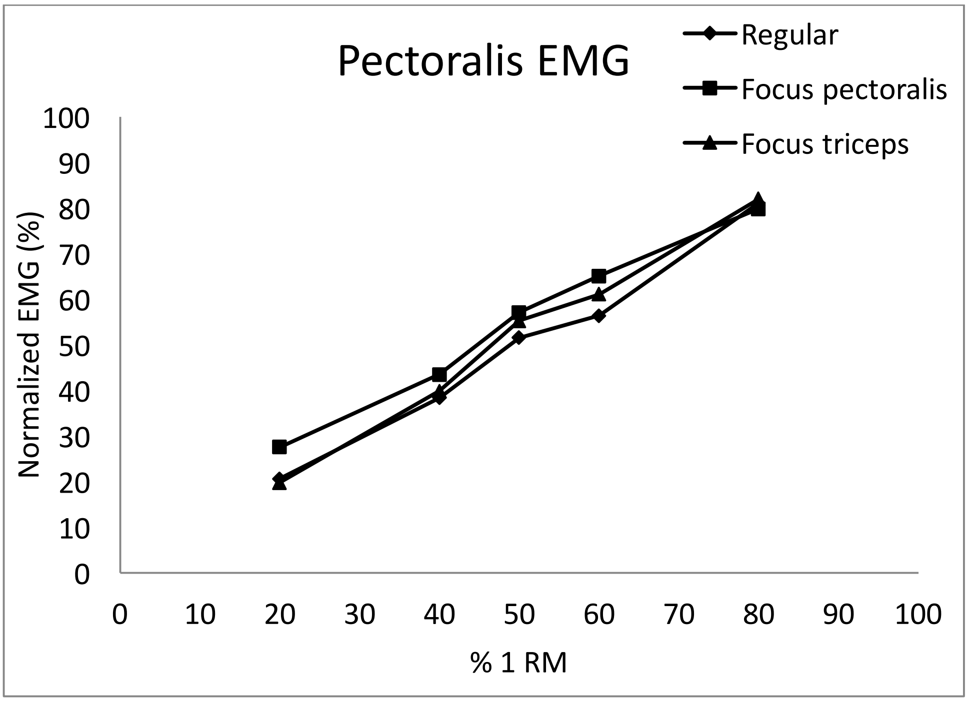

Fig. 2 Illustration of the dose–response relationship between intensity (% of 1RM) and muscle activity (normalized EMG) for the triceps during the three different conditions