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Facultad de Ciencias de la Actividad Física y el Deporte

EFECTOS NEUROMUSCULARES DEL ESTÍMULO VIBRATORIO, EL FENÓMENO DE EFECTO CRUZADO EN PERSONAS SANAS

TESIS DOCTORAL

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Todas las personas que pasan por tu vida dejan una semilla en ella, unas te hacen pensar, otras te hacen vibrar, pero todas ellas marcan tu camino, que es la vida. En los años de estudio y en concreto de esta tesis, ha habido momentos buenos y no tan buenos, en los que siempre hay alguien para apoyarte y para decirte no es tan difícil como tú lo ves, cree en ello, cree en ti, todo tiene solución, tú si puedes,…

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LISTA DE PUBLICACIONES

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GLOSARIO DE ABREVIATURAS

1RM	Una repetición máxima
30Hz-L	Vibración de 30Hz amplitud baja
50Hz-H	Vibración de 50Hz amplitud alta
ANOVA	Análisis de la varianza
BB	Bíceps braquial
cm	Centímetros
CMV	Contracción máxima voluntaria
CTRL	Control
CTRL-30	Carga de 30kg sin vibraciones
CTRL-50	Carga de 50kg sin vibraciones
CTRL-70	Carga de 70kg sin vibraciones
DE	Desviación estándar
ED	Extensor digital
EMG	Electromiografía
EMGrms	Raíz cuadrática media electromiográfica
ES	Tamaño del efecto
FD	Flexor digital
GM	Grastrocnemio medial

Hz	Hercios
ICC	Coeficiente de relación de intraclase
kg	Kilogramos
m	Metros
m·s	Metros por segundo
m·s-2	Metros por segundos al cuadrado
MDF	Frecuencia mediana de la señal electromiográfica
MF	Músculo multífido
min	Minuto
mm	Milímetros
mmp-p	Milímetros de amplitud entre picos
n	Número de participantes
NoWBV	Sin vibración
º	Grados
Post	Después
PP	Potencia máxima
Pre	Antes
RA	Recto abdominal
Rec.	Recuperación

Rep	Repetición
ROM	Rango de movimiento
RTV	Reflejo tónico vibratorio
s	Segundos
SE	Error estándar
sEMG	Señal electromiográfica
VL	Vasto lateral
VMO	Vasto medial oblicuo
W	Vatios
WBV	Vibraciones de cuerpo completo
WBV-30	Carga de 30kg con vibraciones
WBV-50	Carga de 50kg sin vibraciones
WBV-70	Carga de 70kg sin vibraciones
η2	Eta al cuadrado

1. Resumen

Objetivo

El objetivo principal de este proyecto de tesis, es analizar las respuestas del sistema neuromuscular ante la aplicación de vibraciones efectuadas con diferentes modos y medios vibratorios.

Metodología

Se desarrollaron cinco fases experimentales de carácter agudo con sujetos sanos, analizando diferentes variables neuromusculares. En el primer estudio, los sujetos experimentaron tres condiciones diferentes de estímulo vibratorio en apoyo monopodal; tras las cuales, se analizó la potencia de prensa de pierna y la actividad eléctrica muscular de la pierna contralateral. En el segundo estudio, se comparó la fuerza máxima isométrica de presión manual con la actividad muscular durante tres condiciones distintas de estímulo vibratorio, cuerpo completo (WBV), vibración del brazo contralateral (AV), y combinación de las dos anteriores (WBV+AV). En el tercer estudio, se aplicaron diferentes estímulos vibratorios (50 Hz y 30 Hz) durante el ejercicio de *battling rope* simultáneo y alterno, y se estudiaron los efectos neuromusculares. En el cuarto estudio, se analizó la potencia y actividad muscular del press de banca declinado con tres diferentes porcentajes respecto a una repetición máxima (30%, 50% y 70% 1RM) durante la aplicación de WBV. Finalmente, en el quinto estudio, se comparó la movilidad dorsal de tobillo de ambas

piernas tras la aplicación de un masaje con *foam roller* con y sin vibración.

Resultados

En el primer estudio, se observó un efecto condición x pierna x tiempo ($p=0.001$) para la potencia de prensa de pierna en la pierna no estimulada, sin encontrase cambios significativos en la actividad muscular. En el segundo estudio, se encontró una menor coactivación de los músculos extensores digitales en la condición WBV+AV, que en las demás condiciones ($p<0.05$). En el tercer estudio, se observó una mayor activación muscular durante la condición de 50 Hz que para las demás condiciones durante el *battling rope* simultáneo ($p<0.005$). En el cuarto estudio, se apreció que WBV aumentó la potencia pico durante la carga de 70% 1RM ($p<0.001$) en press banca declinado, además de encontrarse un aumento de la activación muscular de los músculos tríceps braquial y bíceps femoral para todas las cargas ($p<0.05$). En el quinto estudio, se encontró un efecto cruzado en la movilidad dorsal de tobillo para la pierna no estimulada con (7%) y sin (6%) vibración ($p<0.001$).

Conclusión

El estímulo vibratorio produce efectos neuromusculares agudos en zonas alejadas del foco vibratorio. Este efecto se ha observado en los miembros no estimulados tras estimulación de forma unilateral, y en las extremidades superiores tras la aplicación de estímulo vibratorio en las extremidades inferiores.

2. ***Abstract***

Objective

The main objective of this thesis in to analyze the neuromuscular responses to vibration stimulus, applied by different ways and systems.

Methods

To this purpose, five different acute experimental periods were developed on healthy subjects, analyzing several muscle variables. On the first study, three different vibration conditions were applied while one leg standing, after that power and muscular activity during contralateral leg press were analyzed. On the second study, hand-grip strength and muscular activity were compared through three different vibration conditions, whole-body vibration (WBV), contralateral arm vibration (AV) and combining the previous two (WBV+AV). On the third study, different vibration stimulus were applied (50 Hz and 30 Hz) while performing a double or alternating battling rope exercise, studying the neuromuscular effects. On the fourth study, power and muscular activity were analyzed during a declined bench press exercise with three different loads of a maximum repetition (30%, 50% and 70% 1RM) while WBV were applied. On the fifth study, ankle mobility of both legs were compared after foam roller massage with and without vibration.

Results

On the first study, an interaction condition x leg x time was observed (p=0.001) for power during non-stimulated leg press, without finding significant changes on muscular activity. On the second study, a lower co-activation of extensor digitalis muscles was found during WBV+AV than the other conditions (p>0.05). On the third study, a greater muscle activity was observed with the 50 Hz condition than the other conditions during double battling rope exercise (p<0.005). On the fourth study, WBV increased peak power on the 70% 1RM load condition (p<0.001) during the declined bench press, moreover an increase on muscle activity of triceps braquialis and biceps femoralis muscles was found for all the loads (p<0.05). On the fifth study, a cross-education effect was found on the ankle mobility of the non-stimulated leg with (7%) and without (6%) vibration (p<0.001).

Conclusion

Vibration stimulus produce acute neuromuscular effects on places located far from the vibration focus, this effect was observed in the non-stimulated areas after a contralateral vibration stimulation, and on the upper body after a lower body vibration stimulus.

3. Introducción

El entrenamiento con vibraciones ha sido investigado a lo largo de las últimas décadas como un método de entrenamiento alternativo o complementario a los programas tradicionales de fuerza para la mejora de la condición física. Las vibraciones de cuerpo completo, en inglés *whole body vibration* (WBV), como método de entrenamiento físico ha experimentado un aumento de su popularidad con diferentes objetivos; salud, terapia física, rehabilitación, deporte de élite y ocio, debido principalmente a sus efectos en el sistema neuromuscular (1). Hablar de vibración es abordar un concepto muy amplio y que puede generar confusión, ya que posee connotaciones negativas en el campo de la medicina laboral (2) y, por el contrario, se relaciona con efectos positivos dentro del área del ejercicio físico y la recuperación funcional. Conocer las características y las dosis de las vibraciones es importante para delimitar los efectos. Por otra parte, el término WBV no es siempre el más apropiado debido a que existen sistemas que aplican el estímulo vibratorio de manera localizada. Por tanto, referirse a este tipo de estímulo como algo que engloba el cuerpo completo podría ser un término aceptado únicamente para describir un tipo de aplicación de vibraciones por medio de plataformas.

Los principales beneficios del entrenamiento con WBV son aumento de la potencia máxima producida (3, 4), y un aumento de

la actividad muscular, lo cual es registrado mediante electromiografía (EMG) superficial (5-7).

a. Concepto de vibración

En términos muy simples, una vibración es un movimiento oscilatorio de pequeña amplitud. Todos los cuerpos poseen una señal de vibración en la que plasman cada una de sus características. Las vibraciones que normalmente se utilizan para el entrenamiento son las senoidales (8) (Figura 1). Estas son las más simples y representan oscilaciones puras. Únicamente hemos encontrado una publicación que haya utilizado la vibración randomizada estacionaria para el entrenamiento (9).

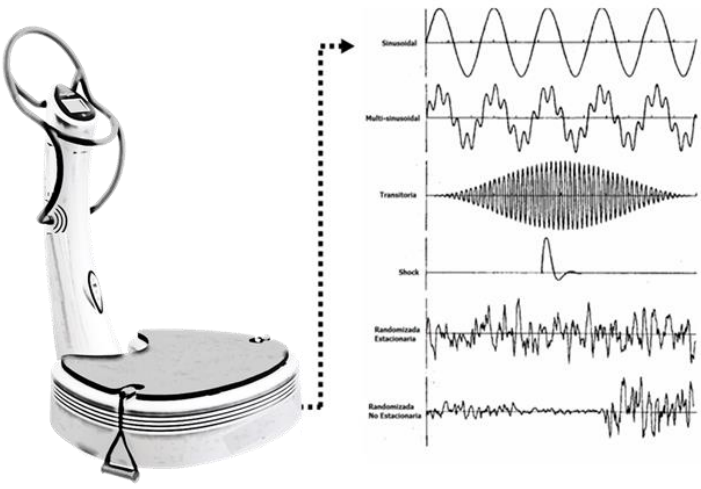


Figura 1. Representación de diferentes tipos de vibración, de arriba a abajo: senoidal, multi-senoidal, transitoria, shock, randomizada estacionaria, y randomizada no estacionaria (modificado de Jordan et al., 2005).

b. Parámetros del estímulo vibratorio

Frecuencia

Frecuencia es el término empleado para indicar el número de veces que se repite cualquier fenómeno periódico en un segundo (10). La frecuencia de las vibraciones se expresa en ciclos por segundo (hertzios, Hz) (Figura 2). El estímulo vibratorio ha sido estudiado con diferentes rangos de frecuencia: con altas (40-200 Hz) (11) y con bajas frecuencias (<50 Hz) (12), registrando la mayor evocación del reflejo tónico vibratorio (RTV) con frecuencia por debajo de 150 Hz. A su vez, en el estudio De Gail et al. (12), fue aplicada la vibración de modo creciente, registrando una disminución de la evocación del RTV cuando la frecuencia estaba próxima a 50 Hz. Por otra parte, otros investigadores han registrado el mayor consumo de oxígeno (VO_2) y activación neuromuscular entre 34 y 30 Hz (5, 13).

En el ámbito del entrenamiento deportivo, las frecuencias más utilizadas son las comprendidas entre 25 y 44 Hz (8). En el estudio realizado por Cardinale & Lim (5) se analizan mediante registro electromiográfico (EMGrms) en el vasto lateral (VL) del cuádriceps, en posición de sentadilla, con 100º de flexión de la articulación de la rodilla, a diferentes frecuencias de vibración, 30, 40 y 50 Hz, con 10mm de amplitud (pico a pico). En estas condiciones, aparecía un aumento mayor de la actividad EMGrms en el VL del cuádriceps a 30Hz con 10 mm de amplitud (pico a pico).

Tras estos estudios, se analizó la actividad EMGrms en 10 estudiantes universitarios, físicamente activos, para los músculos vasto lateral, bíceps femoral, bíceps y tríceps braquial, en los ejercicios de semi-squat y curl de biceps, en contracción isométrica y anisométrica, a diferentes frecuencias (25, 30, 35, 40 y 45 Hz) y amplitudes (2 y 4 mm). Para el vasto lateral, se manifestó un incremento mayor de la EMGrms en dinámico, 3,7 a 8,7%, respecto a la contracción máxima voluntaria (CMV). Para el bíceps femoral, el mayor incremento de la EMGrms fue en isométrico 0,8 a 1,2% de la CMV. Por último, para el tríceps y bíceps, el mayor EMGrms fue dinámico, 0,2-1% y 0,6%-0,8%, respectivamente. Atendiendo a los parámetros de regulación, la máxima respuesta al registro EMG se obtuvo en todos los músculos analizados cuando se aplicaron frecuencias altas (35, 40 y 45 Hz) y 4 mm de amplitud (14).

Existe evidencia previa que afirma que la vibración de WBV de 50 Hz es la más efectiva a la hora de registrar efectos agudos en la musculatura (15).

Amplitud

La amplitud es la distancia entre los extremos alcanzados por el movimiento (valor pico-pico), o también, el recorrido comprendido desde el punto central hasta la desviación máxima (valor pico, o descrito únicamente como amplitud) (Figura 2).

La amplitud de vibración ha sido un parámetro menos estudiado que la frecuencia, pero, del mismo modo, se han desarrollado diversos estudios con diferentes amplitudes. Así, encontramos estudios con amplitudes de 10 mm (16-19) y de 6 mm (16-18, 20), mientras que el rango de amplitud en otros estudios ha oscilado desde 1 a 8 mm (13, 19-23).

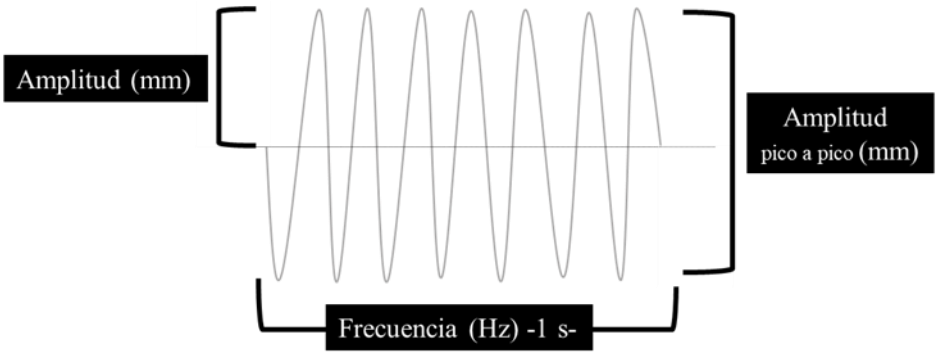


Figura 2. Frecuencia y amplitud de una onda vibratoria senoidal.

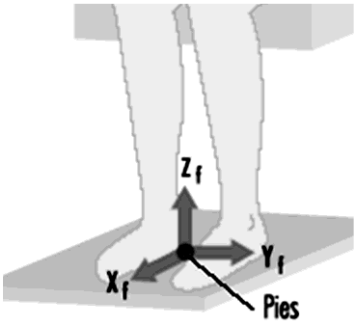
Magnitud

Viene expresada en unidades de aceleración ($m \cdot s^{-2}$), obteniéndose de forma directa mediante acelerómetros o de manera indirecta a partir de la frecuencia (en ciclos por segundo Hz), y la amplitud (en milímetros, mm) (10).

Dirección

Las vibraciones pueden producirse en tres direcciones lineales y tres rotacionales. Los ejes lineales se designan como eje x (longitudinal), eje y (lateral) y eje z (vertical). Las rotaciones

alrededor de los ejes x, y, z se designan como rx (balanceo), ry (cabeceo) y rz (deriva), respectivamente (10). En el caso de la WBV, el eje predominante es el z (Figura 3).



Fuente: ISO 5349, 1986.

Figura 3. Sistema de coordenadas basicéntrico para las vibraciones transmitidas por medio de los pies.

Duración

La respuesta humana a las vibraciones depende en gran medida de la duración total de la exposición a las mismas (10). Existen normativas que determinan el tiempo máximo de exposición, como son la BS 6841 y la ISO 2631, las cuales son consideradas como métodos útiles para cuantificar la intensidad de las vibraciones. Dentro del campo de la rehabilitación y el rendimiento deportivo, el tiempo suele estar comprendido entre 4 y 20 minutos de exposición (13, 17, 24, 25).

Por último, es de suma importancia abordar el concepto de resonancia. De acuerdo con Griffin (10), resonancia es el fenómeno que se produce cuando un cuerpo capaz de vibrar es

sometido a la acción periódica de una fuerza cuyo período de vibración coincide con el período de vibración que caracteriza a dicho cuerpo. Este efecto puede ser destructivo para algunas estructuras. Para evitar que las estructuras del organismo entren en resonancia y puedan lesionarse al trabajar con vibraciones, se deberían utilizar frecuencias mayores de 20 Hz (26).

c. El ejercicio físico y el estímulo vibratorio

El entrenamiento basado en estímulo vibratorio más estudiado ha sido WBV. Normalmente, el ejercicio realizado durante la exposición a vibraciones de cuerpo completo consiste en ejercicios con el peso corporal como sentadillas o zancadas sobre la plataforma con intermitentes estímulos (4, 27). Como ya se ha comentado, WBV produce aumentos de la fuerza y potencia muscular en un breve periodo de tiempo (15). Varios investigadores han estudiado los efectos sobre el rendimiento del entrenamiento con plataforma vibratoria. Estas exposiciones han mostrado diferentes efectos, como aumento en la altura de salto (28), aumento del rendimiento de velocidad (29), cambios metabólicos (13) y hormonales (21), y aumento de la actividad neuromuscular (30), tanto en situaciones agudas (30) como crónicas (23).

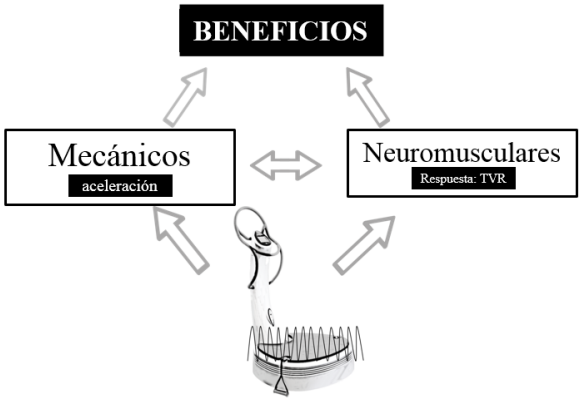


Figura 4. Diagrama ilustrado esquemático de los mecanismos potenciales de los efectos del entrenamiento vibratorio.

El ejercicio realizado sobre una plataforma vibratoria ha demostrado aumentos significativos en la actividad muscular de los miembros inferiores en comparación con los mismos ejercicios realizados sin estímulo vibratorio de cuerpo completo (WBV) (5, 6, 31, 32). La magnitud de esta respuesta neuromuscular depende de la amplitud (tamaño de cada deflexión, medida en mm) y la frecuencia (número de deflexiones por segundo, medido en Hz) del estímulo (33, 34). Durante la realización de un ejercicio isométrico de sentadilla se demostró que cuanto mayor es la frecuencia y la amplitud mayor es la actividad muscular global de los miembros inferiores, en comparación con frecuencias y/o amplitudes bajas (14, 33, 35). Además, la combinación de estímulos vibratorios de alta frecuencia y amplitud ha sido investigada por varios estudios que han demostrado que la exposición en plataforma vibratoria a

un estímulo de alta frecuencia y alta amplitud de forma combinada produce una actividad muscular aún mayor (6, 14, 28). También se ha utilizado la plataforma vibratoria como método de laboratorio para estudiar los efectos negativos de las vibraciones en el rendimiento deportivo en aquellas disciplinas que cuentan con la presencia intrínseca de vibraciones. Por otra parte, deportes de gestos cíclicos repetitivos, como el ciclismo, muestran efectos negativos de las vibraciones sobre el rendimiento, producido por un terreno de superficie irregular (36-39).

Estos hechos sugieren que existe un aumento de la actividad muscular producido por el estímulo vibratorio. Debido al aumento de la popularidad, se han realizado numerosas investigaciones con la intención de comprender si el ejercicio con WBV es beneficioso para todos sus usuarios, y comprender los mecanismos neurofisiológicos y biomecánicos evocados por el estímulo vibratorio.

Las mejoras observadas en la fuerza en las primeras semanas de un programa de entrenamiento, se atribuyen al rendimiento neural, debido a que los cambios en la morfología, arquitectura y tamaño del tejido muscular aparecen en estadios más avanzados (40, 41).

Esta teoría inicial nos lleva a pensar que el ejercicio con WBV mejora las funciones neuromusculares (1, 42-45). Además, se ha evidenciado que el ejercicio con WBV produce aumentos agudos de la fuerza tras una exposición a WBV tras lo cual sugiere una potenciación a nivel neuromuscular (18, 46, 47).

La realización de ejercicios sobre una plataforma de carácter oscilatorio sincrónico (vibraciones verticales uniformes) induce un cambio corto y rápido en la longitud de las fibras musculares provocando una contracción muscular refleja similar a un reflejo monosináptico (7, 34, 48). Esta respuesta produce un aumento de la actividad muscular (6, 31, 32), alcanzando la excitabilidad de la placa cortical motora, además de la modulación de los circuitos intracorticales (49). El estímulo vibratorio mecánico también puede afectar a los receptores cutáneos y articulares que dan una mayor respuesta sensorial al sistema gamma motor aumentando la sensibilidad y respuesta muscular ante perturbaciones mecánicas (16, 50).

El aumento de la actividad musculoesquelética provoca que la demanda metabólica para la actividad incremente, lo cual fue evidenciado con u aumento del consumo de oxígeno / gasto energético debido a la exposición a WBV (13, 51-53); sin embargo, la magnitud de este aumento de demanda es mucho menor que la requerida por un entrenamiento de fuerza tradicional (6). Por lo tanto, el estímulo vibratorio de cuerpo completo tiene el potencial de incrementar los efectos de diferentes ejercicios realizados sobre la plataforma vibratoria, como ha sido mostrado por diferentes investigadores y profesionales sanitarios (45)

También, el estímulo de WBV produce aumentos en la actividad muscular durante actividades dinámicas, ya que se demostró que el ejercicio de sentadilla con una carga externa adicional (~30% del peso corporal), comparado con la condición sentadilla sin carga

adicional, pero con estímulo vibratorio de cuerpo completo aumentaba o igualaba la actividad muscular (6, 33). Estos resultados demuestran la vinculación del aumento de la actividad musculoesquelética con la exposición a un estímulo WBV, la cual no disminuye con la incorporación de una carga externa.

d. Sistemas para producir el estímulo vibratorio

Como podemos apreciar en la figura 5, existen diferentes dispositivos para generar la vibración. El estímulo vibratorio puede ser aplicado de forma local (54), mediante dos formas diferentes (i) directamente sobre el vientre muscular (55) o sobre el tendón muscular (56, 57), o bien, (ii) indirectamente aplicado por un sistema vibratorio de prensa manual (58), con mancuerna (59), con barra (60) o un sistema de poleas (24).

Como ya se ha mencionado, el estímulo vibratorio que es aplicado a través de los pies mientras se está en posición de bipedestación sobre una plataforma vibratoria (61) es conocido como vibraciones de cuerpo complete (WBV). Un estudio reciente ha demostrado que un sistema de vibración portátil denominado *wearable vibration* aumenta el pico de potencia máximo en los flexores de codo en atletas (62). Este sistema dispone de batería portátil recargable y puede autoaplicarse, lo cual supone un avance al equipo de entrenamiento con vibraciones. Además, otro estudio ha mostrado que, la estimulación con este tipo de sistema por un corto periodo de tiempo reduce los niveles de dolor en el

bíceps braquial a las 24h, 48h y 72h y reduce significativamente la creatinkinasa a las 72h de la exposición en comparación con la situación control (63).

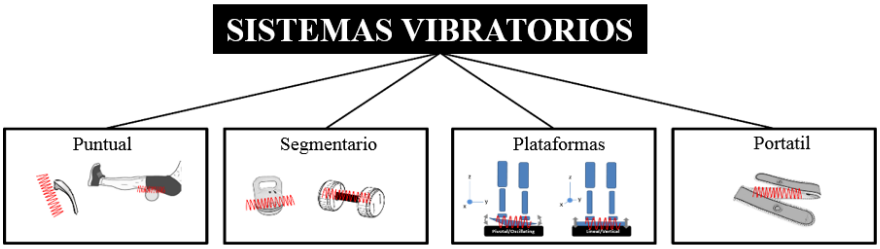


Figura 5. Los sistemas vibratorios diseñados por varios productores y utilizados en investigaciones clínicas.

e. El estímulo vibratorio y el desarrollo de la fuerza

La utilización de plataformas vibratorias en la forma más común de ejercicio a la hora de estudiar las adaptaciones a la fuerza. Como ya se ha comentado, existen dos tipos de plataformas vibratorias: las plataformas cuya vibración es predominantemente en sentido dirección vertical (plataforma vertical) y las plataformas cuyas vibraciones consisten en rotaciones en torno a un eje horizontal (plataforma oscilante), en este último caso, cuanto mayor es la distancia de eje de rotación, mayor es la amplitud de la vibración (64).

Lamont et al. (65) encontraron un incremento significativo en la fuerza durante un test isométrico de sentadilla tras la realización

de un entrenamiento de fuerza con estímulo vibratorio de tipo WBV simultáneo.

Marín y Rhea (27) publicaron un meta-análisis en el cual analizaban la magnitud de fuerza aguda y crónica ganada con el entrenamiento de vibraciones y examinaron factores específicos que influían en los efectos del tratamiento. Los resultados de este análisis mostraron diferencias en la fuerza muscular aguda y crónica, entre una plataforma vibratoria vertical y una plataforma vibratoria oscilante. Las plataformas de vibración verticales producen un mayor efecto en relación a las adaptaciones crónicas (ES = 1.24) en comparación con las plataformas vibratorias oscilantes (ES = -0.13). Por otra parte, las plataformas oscilantes producen mayores efectos agudos (ES = 0.24) en comparación con las plataformas verticales (ES =-0.07).

Los datos de este estudio también demostraron que existen determinantes del desarrollo de la fuerza ante el ejercicio con vibraciones (plataforma vibratoria vertical), como son: la edad (jóvenes ES = 1.18 y mayores ES = 1.83), el sexo (las mujeres experimentaron un mayor aumento de la fuerza con el entrenamiento de vibraciones que los hombres), la condición física, y el protocolo de ejercicio (los datos demostraron que la combinación de varios tipos de contracciones musculares producían el doble de adaptaciones que los ejercicios isométricos). Además, el entrenamiento con vibraciones es efectivo para producir adaptaciones a largo plazo de la fuerza muscular (27).

Por lo tanto, el ejercicio con vibraciones puede ser utilizado por profesionales de ciencias del deporte para aumentar la fuerza muscular.

f. El estímulo vibratorio y el desarrollo de la potencia

En relación a la potencia, existe evidencia de que de forma aguda el estímulo de WBV incrementa la fuerza y la potencia en un salto bilateral con contramovimiento (46, 66, 67), en una sentadilla con medición de la potencia (68), en un test isocinético unilateral de extensión de rodilla (67). Fue registrado un aumento de la velocidad (5-7%) durante el ejercicio de prensa de pierna monopodal con carga (70-130 kg) tras la aplicación unilateral de WBV (10 x 60 s) (18); que consistió en la medición de la velocidad de ejecución de la pierna estimulada y no estimulada tras una vibración de 50 Hz y alta amplitud. Además, es evidente que los mayores picos de aceleración se producen con cargas bajas (69).

g. El estímulo vibratorio y el fenómeno cruzado (cross education)

El estudio realizado por Scripture et al. (70) fue el primer estudio que encontró un aumento en la fuerza de una extremidad tras la realización de un entrenamiento de resistencia en el miembro contralateral (70). Tras ese estudio, otras investigaciones han

observado cambios en la fuerza en el miembro que no está entrenando (71) tras un entrenamiento del miembro contralateral; la mayoría de estos estudios han sido realizados sobre los extensores de rodilla (72, 73) y los flexores de codo (74, 75). Shima et al. (76) encontraron un efecto cruzado en los flexores plantares tras un entrenamiento de 6 semanas en el que se realizaban flexiones plantares monopodales en una plataforma de pie.

El efecto del *cross education* puede producirse tanto en los músculos del tren superior como los del tren inferior, desde los músculos más pequeños e intrínsecos como los de la mano, a los más grandes, como los músculos ambulatorios de las piernas, cuádriceps y sóleos (76, 77).

El fenómeno de *cross education* depende de las proyecciones corticoespinales directas e indirectas (78).

Puede producirse *cross education* con entrenamiento de carácter voluntario o con estimulación eléctrica muscular (79), sin recibir ningún tipo de estímulo en el miembro no entrenado y, por lo tanto, este miembro no experimenta un aumento del volumen muscular o hipertrofia.

También puede producirse a través de diferentes métodos de entrenamiento, ya sean isométricos (77) o dinámicos (71), y sigue los principios del entrenamiento, de esta forma, las ganancias de fuerza obtenidas por el entrenamiento unilateral se transfieren al miembro contralateral no entrenado provocando una ganancia de

fuerza proporcional al miembro entrenado, en el mismo movimiento o ejercicio (71, 80).

h. El estímulo vibratorio y la movilidad articular

La movilidad articular o rango articular de movimiento nos permite realizar los movimientos de la vida diaria y deportiva de forma dinámica, homogénea, diversa, amplia y precisa. Una buena movilidad dorsal de tobillo es fundamental para el equilibrio y estabilidad de tobillo (81). Una de las lesiones más comunes de miembro inferior es el esguince de tobillo, cuyo índice de recidiva es muy alto (82), provocado por una insuficiente recuperación de la movilidad dorsal de tobillo (83, 84) y estabilidad del mismo (85-87). Por lo que, una correcta rehabilitación de tobillo mejorará la movilidad del mismo y garantizará una disminución en el riesgo de recidiva (81).

La evidencia científica ha demostrado que la autoliberación miofascial es una intervención efectiva para aumentar el rango articular (88); sin embargo, no se dispone de un programa definido, debido principalmente a la heterogeneidad metodológica encontrada en los diferentes estudios (89). Para el aumento del rango de movimiento articular existen diferentes métodos basados en el estiramiento como son los estiramientos estático, dinámico y balístico, así como la técnica de facilitación neuromuscular propioceptiva (90). El estiramiento estático es un estiramiento comúnmente utilizado; sin embargo, se ha demostrado que su

utilización dentro del calentamiento y preparación para el ejercicio produce una disminución significativa en la potencia y, por lo tanto, en el rendimiento deportivo (91). Se ha investigado que en relación al tejido muscular encontramos un tejido conectivo denominado tejido miofascial o fascia (90), que puede restringir el rango de movimiento y disminuye la fuerza y resistencia muscular si dicho tejido se encuentra alterado, lesionado, inflamado o inactivo (92). En lugar de la utilización de técnicas como la osteopatía, manipulaciones, integración estructural, masaje de diferentes formas, técnicas de energía muscular y técnica Graston® para tratar la fascia (93), una técnica alternativa, es la autoliberación miofascial para aumentar el rango de movimiento articular (88, 94) la cual puede ser facilitada por un *foam roller* (90).

El masaje con *roller* o *foam rolling* es una técnica, utilizada para la autoliberación miofascial, muy extendida en la última década. La autoliberación miofascial ha sido utilizada en rehabilitación de lesiones musculoesqueléticas y en el rendimiento deportivo con el objetivo de aumentar la movilidad miofascial. Algunos estudios previos, han concluido que esta técnica puede aumentar la movilidad articular (92) y mejorar el proceso de recuperación tras un esfuerzo físico (95).

Por otra parte, el ejercicio puede producir un efecto muscular doloroso, conocido como agujetas; el término anglosajón es *delayed onset muscular soreness* (DOMS) (96); esta sensación aparece tras un ejercicio inusual o con gran componente excéntrico. El masaje con *foam roller* ha demostrado que es

efectivo para reducir esta sintomatología (97) adquirida tras el esfuerzo (98).

4. Objetivos

A la vista del estado actual del conocimiento sobre el estímulo vibratorio, así como de los medios y métodos de aplicación, nos hemos propuesto desarrollar una serie de intervenciones cuyo objetivo principal es analizar las respuestas del sistema neuromuscular ante la aplicación de vibraciones, efectuadas con diferentes modos y medios de aplicación.

A partir de este objetivo general se ha propuesto la realización de cinco estudios en donde se han planteado diferentes objetivos específicos:

I. Analizar los efectos neuromusculares agudos del fenómeno cruzado mediante la aplicación del estímulo vibratorio en sujetos sanos.
II. Determinar los efectos neuromusculares agudos que producen varios focos vibratorios frente a un único foco vibratorio.
III. Estudiar los efectos neuromusculares agudos de la combinación de un ejercicio de miembros superiores con estimulación vibratoria de cuerpo completo.
IV. Conocer la potencia y actividad neuromuscular aguda de un press de banca con diferentes cargas durante la aplicación de un estímulo vibratorio en los miembros inferiores.
v. Analizar los efectos agudos del fenómeno cruzado sobre la movilidad dorsal y la fuerza de flexo-extensión tras la

aplicación de un estímulo vibratorio sumado al masaje con *foam roller* sobre el tobillo.

5. Hipótesis

La hipótesis principal de esta tesis ha sido que el estímulo vibratorio potenciaría el sistema neuromuscular mejorando el rendimiento.

Las hipótesis específicas han sido:

I. La aplicación del estímulo vibratorio producirá un efecto neuromuscular cruzado en miembro inferior no estimulado en sujetos sanos.
II. Varios focos vibratorios producirán mayores efectos neuromusculares que un único foco vibratorio.
III. La combinación de un ejercicio de miembros superiores con la estimulación vibratoria de cuerpo completo incrementará los efectos neuromusculares agudos.
IV. La aplicación de un estímulo vibratorio en los miembros inferiores aumentará la potencia y actividad neuromuscular aguda de un press banca con diferentes cargas.
V. El estímulo vibratorio sumado al masaje con *foam roller* de la musculatura flexora dorsal producirá aumentos de la movilidad de dorsal observándose fenómeno cruzado sin generar cambios en la fuerza de flexo-extensión del tobillo.

I

6. Artículo I

I. Título

El ejercicio agudo unilateral con vibraciones mejora el rendimiento neuromuscular de la pierna contralateral.

II. Title

Acute unilateral leg vibration exercise improves contralateral neuromuscular performance.

III. Resumen

Objetivo: Examinar los efectos cruzados tras el ejercicio agudo con WBV. Metodología: Diecisiete voluntarios hombres (20.8±1.2 años) realizaron tres condiciones de vibración unilateral en orden aleatorio: 1) WBV-50 Hz [amplitud alta] 2) WBV-30 Hz [amplitud baja]; y 3) condición control sin WBV (Sham) aplicado sobre la pierna dominante. Cada condición incluyó una contracción máxima voluntaria (CMV) seguida de tres repeticiones explosivas de prensa de pierna (40% CMV) con las piernas no-dominante y dominante; las cuales se realizaron antes y después de la vibración (inmediatamente; 2 min y 5 min). Durante cada condición se registró la actividad electromiográfica (EMG) del vasto lateral (VL) y del gastrocnemio medial (GM). Resultados: Se detectó un efecto de interacción condición x pierna x tiempo (p=0.001) donde la condición de 50 Hz-High en la pierna estimulada aumento la velocidad media en post-2 min en comparación con 30 Hz-Low y

Sham, manteniéndose elevado hasta post-5 min. De forma similar, en la pierna no estimulada, la condición 50Hz-High aumentó la velocidad media en inmediatamente después y post-2 min comparado con 30 Hz-Low y Sham. No hubo cambios en EMG para VL y GM en las piernas estimulada y no-estimulada en las condiciones post. Conclusión: WBV (50Hz) puede aumentar el rendimiento neuromuscular de forma cruzada. WBV puede ser un método de entrenamiento unilateral alternativo para incrementar la fuerza explosiva cruzada.

IV. Abstract

Objectives: To examine the post-exercise cross-transfer effects of acute WBV. Methods: Seventeen healthy male volunteers (20.8±1.2 y) performed three unilateral vibration conditions in a randomized order: 1) WBV-50 Hz [high amplitude] 2) WBV-30 Hz [low amplitude]; and 3) a control no WBV condition (Sham) applied to the dominant leg. Each condition involved maximal voluntary isometric contractions (MVC) followed by three leg press explosive repetitions (40% MVC) with non-dominant and dominant legs; which were conducted prior to and post vibration (immediately; 2 min and 5 min). Surface electromyography (EMG) of the vastus lateralis (VL) and medial gastrocnemius (GM) were measured throughout each condition. Results: A condition x leg x time interaction effect was detected (p=0.001) where 50 Hz-High in the stimulated leg enhanced mean velocity at post-2 min compared to

30 Hz-Low and Sham, remaining elevated at post-5 min. Similarly, 50 Hz-High in the non-stimulated leg increased mean velocity at post-immediately and post-2 min compared to 30 Hz-Low and Sham. There were no changes in EMG of VL and GM in the stimulated and non-stimulated post-conditions. Conclusion: WBV (50 Hz) can augment cross-transfer in neuromuscular performance. WBV could provide an alternate method of unilateral training to promote cross education explosive strength.

V. Metodología

a. Diseño experimental

Este estudio investigó si la exposición a un estímulo vibratorio de cuerpo completo (WBV) de 30 s en posición de semi-sentadilla monopodal aumenta el rendimiento muscular de la pierna contralateral que no recibe estimulación. Se registró la actividad muscular y el rendimiento muscular mediante un test explosivo de prensa de piernas con el 40% de la contracción máxima voluntaria (MVC), antes, inmediatamente después (menos de 30 s), a los 2 y a los 5 min después de la exposición al estímulo WBV. Se realizaron de forma aleatoria tres condiciones distintas (variables independientes): 1) 50 Hz amplitud alta (50 Hz-High), 2) 30 Hz amplitud baja (30 Hz-Low), y 3) sin WBV (Sham). Todas las condiciones estuvieron separadas por al menos 2 días y se realizaron a la misma hora del día para evitar efectos por los ritmos circadianos. Al final del estudio, los participantes habían realizado

las tres condiciones. La pierna dominante de cada participante fue determinada por la preferencia a la hora de golpeo de un balón.

b. Participantes

Diecisiete estudiantes hombres participaron en este estudio (20.8±1.2 años de edad, 179.7±0.2 cm de altura, 76.0±8.5 kg de masa corporal, media±DE). Cada participante realizo las 3 condiciones con el objetivo de minimizar la variabilidad interindividual en la respuesta neuromuscular; 15 de los 17 participantes eran diestros de pierna. Todos los participantes eran físicamente activos y ninguno comenzó un programa de entrenamiento sistemático durante la recogida de datos o al menos 2 meses antes del inicio del estudio. Los participantes tenían experiencia en los ejercicios de fuera con peso libre y con el entrenamiento al fallo. Antes de comenzar el estudio, los participantes recibieron información sobre el estudio y los requerimientos del mismo y firmaron un consentimiento informado. Los criterios de exclusión fueron padecer diabetes, epilepsia, piedras en la vesícula o en el riñón, enfermedades cardiovasculares, prótesis articulares, trombosis reciente, así como problemas musculoesqueléticos. Se solicitó a los participantes el mantenimiento de los hábitos de dieta, sueño y bebida durante el estudio. Una semana de las sesiones de registro, los participantes realizaron dos sesiones de familiarización. El proyecto de investigación se realizó de acuerdo a la Declaración

de Helsinki y fue aprobada por el Gabinete de Asuntos humanos de la Universidad.

c. Sistema de vibración

La plataforma vibratoria utilizada para la aplicación del estímulo vibratorio (Power Plate®Next Generation pro 5, Power Plate North America, Northbrook, Illinois, USA) producía oscilaciones uniformes en los tres planos de movimiento (99). La aceleración del eje vertical (eje-z) se midió utilizando un acelerómetro de eje único de acuerdo con ISO2954 Vibration meter VT-6360, Hong Kong, China). Los parámetros de la plataforma vibratoria incluían una frecuencia de 50 Hz con un desplazamiento pico a pico de 2.51 mm de amplitud (High) o una frecuencia de 30 Hz con un desplazamiento pico a pico de 1.15 mm de amplitud (Low). Las medidas de aceleración fueron 100.6±0.24 $m \cdot s^{-2}$ (para 50 Hz) y 20.44±0.34 $m \cdot s^{-2}$ (para 30 Hz). Durante todas las condiciones los participantes llevaban el mismo calzado deportivo con el objetivo de estandarizar la absorción de vibraciones por el calzado (32).

d. Medición del rendimiento neuromuscular

Los participantes realizaron durante todas las sesiones experimentales, unas contracciones isométricas máximas voluntarias (CMV) con 60º de flexión de rodilla, seguidos de una contracción dinámica explosiva con el 40% de MVC, en una

máquina de prensa de pierna (Nautilus Strength System S912, Vancouver, Canadá), se realizaron tanto con la pierna no dominante como con la dominante. Para las contracciones isométricas MVC se solicitó a los participantes que contrajeran lo más fuerte y rápido posible durante 3 s aproximadamente. Este procedimiento se repitió tres veces por cada pierna con un descanso de 20 s. Para la medición de la MVC se utilizó una célula de carga digital colocada en el cable del equipo de Nautilus. Tras esto, los participantes descansaban durante 5 min antes de realizar las 3 contracciones dinámicas explosivas por cada pierna con el 40% de MVC, separadas por 20 s, los participantes debían extender la pierna lo más rápido y fuerte posible durante 3 s. El investigador principal daba órdenes verbales con el objetivo de asegurarse que se mantenía una correcta ejecución durante el test. El rendimiento muscular de cada repetición explosiva fue registrado por un encoder (Globus Real Power, Globus, Codogne, Italy) rotacional anclado a la base de carga. Este encoder rotacional registraba la posición de la carga con una precisión de 0.1 mm y el tiempo con una precisión de 0.001 s. Se analizó la velocidad media de cada repetición. La velocidad se determinó mediante un programa específico para el encoder rotacional como se ha descrito anteriormente (100, 101).

e. Actividad electromiográfica superficial (EMG)

Se midió la actividad muscular del vasto lateral (VL) y del gastrocnemio medial (GM) con electromiográfica superficial (EMG) (6, 31, 32, 102, 103). Antes de colocar los electrodos, se afeitaba y limpiaba la zona con alcohol con el objetivo de reducir la impedancia de la piel. Los electrodos se colocaron en el medio del vientre muscular de forma paralela a la dirección de las fibras, siguiendo las recomendaciones del proyecto SENIAM (Surface ElectroMyo-Graphy for the Non-Invasive Assessment of Muscles) (104).

Las señales mioeléctricas crudas se registraban utilizando la técnica diferencial doble. Los electrodos superficiales estaban conectados a un convertidor 16-bit AD (TrigoTMWireless System, Delsys Inc., Boston, MA, USA). Se pre-amplificaban las señales en crudo junto a los electrodos (amplitud de señal de 20-450 Hz) a 4000 Hz y se almacenaban en un portátil. Para el análisis de las señales EMG se utilizó un programa específico (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, Massachusetts, USA). Para obtener la amplitud media de la señal de EMG, se obtuvo la raíz cuadrática media (rms) de los datos de EMG. Se normalizaron los valores obtenidos de EMGrms en el test de explosividad con el 40% de MVC tras la aplicación del estímulo o condición, con respecto al test previo a la intervención. Se registraron también 20 s de EMG durante la aplicación del estímulo (desde 5 s a 25 s), los cuales se normalizaron en relación a los valores obtenidos durante el test isométrico de MVC (6, 14, 31, 32).

f. Protocolo

Todas las sesiones experimentales comenzaban con un calentamiento que consistió en pedalear en un cicloergómetro durante 5 minutos con una resistencia baja (75 W). Las tres condiciones que realizaron todos los participantes de forma aleatoria y separada fueron: 1) 50Hz-High (vibración de 50Hz y amplitud alta); 2) 30Hz-Low (vibración de 30Hz amplitud baja); 3) situación control sin aplicación de WBV (Sham). Cada sesión comenzó con el test isométrico de MVC y test de explosividad con el 40% del MVC tras 5 min de recuperación (Figura 6). El tratamiento experimental consistió en la estimulación con WBV en apoyo monopodal de la pierna dominante, cuyo pie se colocaba en el centro de la plataforma manteniendo una posición de sentadilla estática con 60º de flexión de rodilla, durante 30 s, (rodilla totalmente extendida = 0º), que se midió con un goniómetro manual. La pierna no estimulada (no dominante) se mantuvo fuera de la plataforma (Figura 7), para mantener el equilibrio se permitía el contacto manual con los agarres. El tiempo entre la condición y el post-test no fue mayor de 5 s.

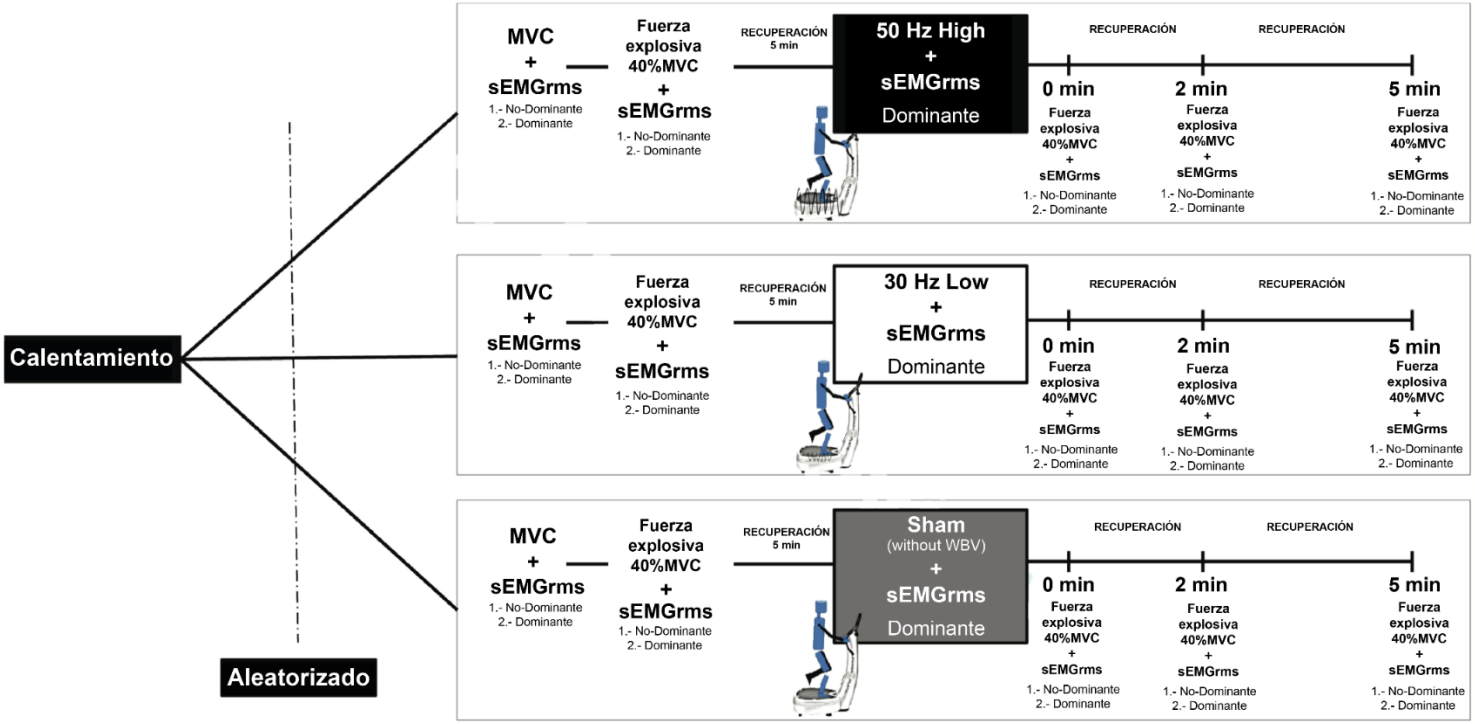


Figura 6. Diseño experimental del estudio I.

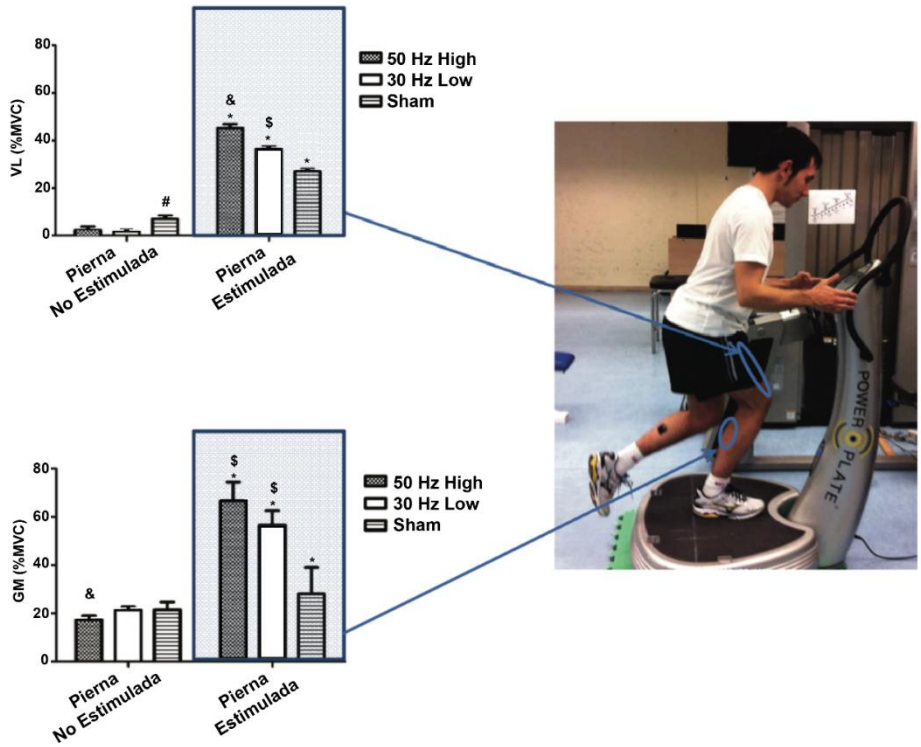


Figura 7. EMGrms del vasto lateral (VL) y el gastrocnemio medial (GM) durante la aplicación de estímulo WBV unilateral. * Estadísticamente significativo entre piernas ($p<0.001$); $^{\#}$ Estadísticamente significativo de 50Hz-High y 30Hz-Low ($p<0.001$); $^{\&}$ Estadísticamente significativo de Sham y 30Hz-Low ($p<0.001$); $^{\$}$ Estadísticamente significativo de Sham ($p<0.001$).

g. Análisis estadístico

Se realizó el test Shapiro-Wilk para comprobar la normalidad de los datos. Las variables dependientes se evaluaron con el análisis de varianza de medidas repetidas (ANOVA) para las tres variables

tiempo x condición x pierna. Se aplicó el procedimiento Bonferroni post hoc para los valores significativos estadísticamente en el valor F, con el objetivo de realizar la comparación por pares. El nivel de significación se fijó en $p \leq 0.05$. Se calculó el coeficiente de correlación intraclase (ICC) de la velocidad máxima y velocidad media de las contracciones dinámicas explosivas con el 40% de MVC para cada pierna, con el objetivo de determinar la fiabilidad test-retest. El ICC fue mayor de 0.92, lo cual indica que las mediciones de las variables dependientes tienen una reproducibilidad de alto nivel. Los valores se expresaron en media±DE y el tamaño del efecto se midió en Eta cuadrado parcial (η^2).

VI. Resultados

La Tabla 1 muestra los resultados de las interacciones de 2 y 3 direcciones y del análisis ANOVA de las variables dependientes.

Tabla 1. Resumen de los principales efectos analizados con ANOVA para las variables dependientes.

	Velocidad Media	VL sEMGrms	GM sEMGrms
Condición	p=0.091; n^2=0.139	**p=0.029; n^2=0.224**	p=0.717; n^2=0.030
Pierna	**p=0.002; n^2=0.465**	p=0.121; n^2=0.163	p=0.298; n^2=0.098
Tiempo	**p=0.002; n^2=0.264**	p=0.367; n^2=0.072	p=0.610; n^2=0.053
Condición*Pierna	p=0.088; n^2=0.141	p=0.575; n^2=0.039	p=0.420; n^2=0.076
Condición*Tiempo	**p<0.001; n^2=0.244**	p=0.139; n^2=0.107	p=0.255; n^2=0.108
Pierna*Tiempo	p=0.159; n^2=0.101	p=0.115; n^2=0.130	p=0.158; n^2=0.144
Condición*Pierna*Tiempo	**p=0.001; n^2=0.208**	p=0.850; n^2=0.031	**p=0.029; n^2=0.187**

Tabla 2. Velocidad media (m·s-1) de Pre y Post para las tres condiciones.

	50Hz-High		30Hz-Low		Sham	
	No-Estimulada	**Estimulada**	**No-Estimulada**	**Estimulada**	**No-Estimulada**	**Estimulada**
Pre	0.296±0.01	0.315±0.01	0.288±0.02	0.299$±0.01	0.285±0.02	0.302±0.01
Post-Inmediato	0.312*#±0.01	0.325*±0.01	0.289±0.02	0.288*&±0.01	0.279±0.02	0.303±0.02
Post 2 min	0.309*±0.01	0.329*±0.01	0.289±0.02	0.306±0.01	0.288±0.02	0.309±0.02
Post 5 min	0.302±0.01	0.331*±0.01	0.282*±0.02	0.296&±0.01	0.288±0.02	0.285*±0.02

$ - Estadísticamente significativo entre pierna para sesiones experimentales ($p<0.05$).
* - Estadísticamente significativo de Pre en la misma pierna y sesión experimental ($p<0.05$).
& - Estadísticamente significativo de Post 2 min en la misma pierna y sesión experimental ($p<0.05$).
# - Estadísticamente significativo de Post 5 min en la misma pierna y sesión experimental ($p<0.05$).

a. Rendimiento neuromuscular

Se observó un efecto pierna principalmente indicando que la pierna estimulada producía una velocidad media mayor que la pierna no dominante (p=0.002). También, se encontró un efecto tiempo significativo en el cual el post test tras 2 min (post-2 min) de la exposición producía mayores valores de velocidad media que los demás momentos de medición (pre, post-inmediato y post-5min), p=0.002). Se encontró un efecto significativo en la interacción de condición y tiempo (p<0.001) indicando que la condición 50Hz-High a los 2 min de exposición producía los mayores aumentos de velocidad media (Tabla 2). También se encontró un efecto significativo en la interacción de condición x pierna x tiempo (p=0.001) en la que la condición 50Hz-High a los dos minutos de exposición en la pierna estimulada se producían valores de velocidad media mayores en comparación con las condiciones 30Hz-Low y Sham, manteniéndose dicha elevación a los 5 min de la exposición. De igual manera, la condición 50Hz-

High produjo un aumento en la velocidad media de la pierna no estimulada tanto para el test realizado inmediatamente después como para 2 min después de la exposición, en comparación con las con 30Hz-Low y Sham. Los porcentajes de cambio de la velocidad media se pueden ver en la figura 8.

b. Actividad muscular durante la estimulación con WBV unilateral

La actividad EMG del VL y del GM fue incrementada durante la exposición a WBV, en comparación con la condición Sham y con la pierna no estimulada, se registró mayor EMG en el VL durante la condición 50Hz-High que durante la condición 30Hz-Low. No se registraron diferencias significativas en la actividad muscular del GM durante las condiciones 50Hz-High y 30Hz-Low (Figura 8).

c. Actividad muscular tras la aplicación de WBV

No hubo cambios significativos en EMG para VL y GM tras la exposición a estímulo WBV indicando que EMG no aumento suficientemente tanto en la pierna dominante como no dominante (Figura 8). Sin embargo, hubo un efecto significativo respecto a condición por el cual la condición Sham aumento significativamente ($p<0.05$) la EMG del VL en comparación con la condición 30Hz-Low (Tabla 3). También, se registró un efecto significativo ($p<0.05$) en la interacción condición x pierna x tiempo

para EMG del GM en la pierna no estimulada, en el cual el valor fue menor a los 5 minutos de la exposición para la condición 30Hz-Low en comparación con la condición Sham (Tabla 4).

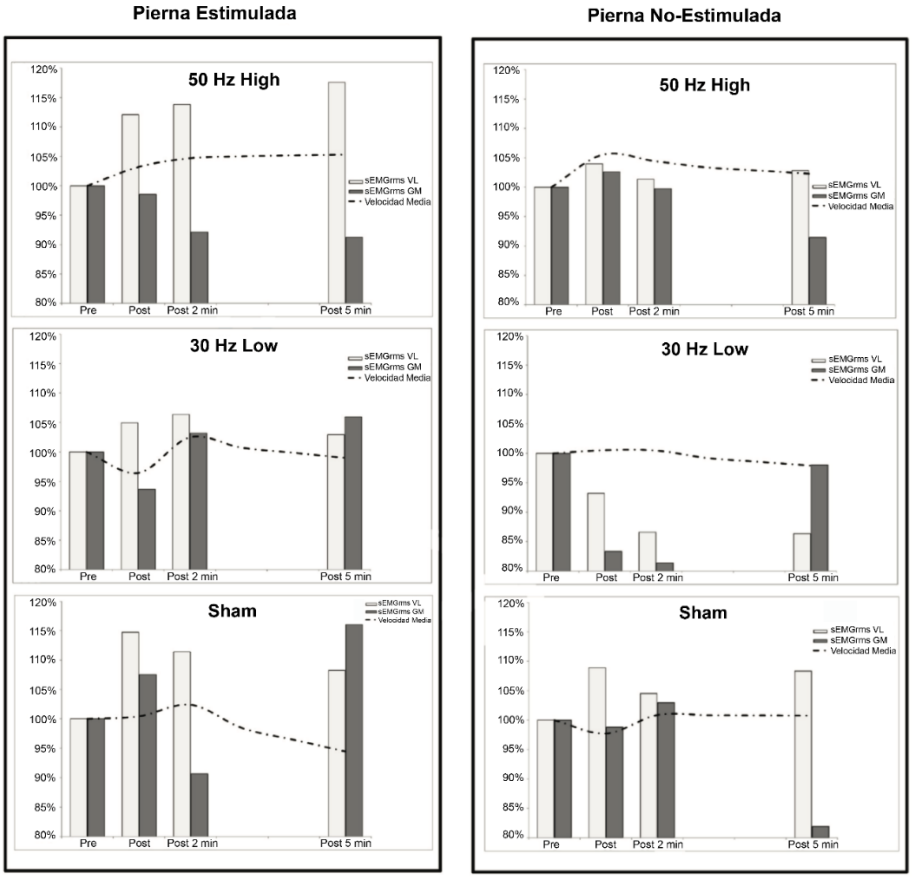


Figura 8. Porcentaje de cambio para velocidad media y EMG de vasto lateral (VL) y gastrocnemio medial (GM).

Tabla 3. EMG de VL (%) de Pre y Post para las tres condiciones.

	50Hz-High		30Hz-Low		Sham	
	No-Estimulada	**Estimulada**	**No-Estimulada**	**Estimulada**	**No-Estimulada**	**Estimulada**
Pre	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0
Post-Inmediato	102.6±7.6	98.6±5.8	83.4±11.1	93.7±4.4	98.8±11.2	107.5±10.3
Post 2 min	99.8±8.0	92.1±9.1	81.4±6.8	103.2±4.7	103.0±10.4	90.7±4.4
Post 5 min	91.5±7.6	91.2±9.8	98.0±14.2	106.0±5.1	81.9±10.1	116.0±5.4

Tabla 4. EMG de GM (%) de Pre y Post para las tres condiciones.

	50Hz-High		30Hz-Low		Sham	
	No-Estimulada	**Estimulada**	**No-Estimulada**	**Estimulada**	**No-Estimulada**	**Estimulada**
Pre	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0
Post-Inmediato	104.0±9.0	112.1±5.5	93.2±9.2	105.0±7.5	108.9±5.1	114.7±6.5
Post 2 min	101.4±9.0	113.8±7.0	86.6±7.0	106.4±10.3	104.5±5.4	111.4±5.2
Post 5 min	102.8±9.0	117.6±7.0	86.4±5.9	102.9±10.6	108.3±5.6	108.2±6.5

II

7. Artículo II

I. Título

Comparación de diferentes técnicas de ejercicio con vibración en el rendimiento neuromuscular.

II. Title

A comparison of different vibration exercise techniques on neuromuscular performance.

III. Resumen

Objetivos: El primer objetivo de este estudio fue determinar los efectos del ejercicio con WBV durante una tarea de prensión manual. El segundo objetivo fue evaluar si más de un foco vibratorio produciría mayores efectos que un solo foco vibratorio. Este estudio investigó la exposición de WBV durante 10 repeticiones de prensión manual con dinamómetro en bipedestación sobre la plataforma de WBV. Metodología: Veintiocho estudiantes activos completaron 3 diferentes condiciones, en orden aleatorio: 1) ejercicio de dinamometría manual con WBV y vibración del brazo contralateral (WBV+AV); 2) únicamente vibración del brazo contralateral (AV); 3) dinamometría manual sin vibración (Control). Resultados: La fuerza de prensión fue ligeramente mayor en la condición WBV+AV en comparación con las condiciones Control y AV (1.1% y 3.6%, $p>0.05$, respectivamente). Se observó un principal efecto de EMGrms en

el músculo extensor digital (ED) indicando que ña condición WBV+AV produce una menor coactivación de ED durante una tarea de flexión de dedos, que las condiciones Control y AV ($p<0.05$). Conclusión: La aplicación de WBV+AV puede aumentar de forma aguda la coordinación muscular y disminuir la coactivación de ED. Además, la EMGrms muscular muestra un aumento en la activación cercana al foco vibratorio tanto en miembros superiores como inferiores.

IV. Abstract

Objectives: The first purpose of this study was to determine the effects of whole-body vibration (WBV) exercise during an isometric handgrip exercise. The second purpose was to evaluate whether more than one vibratory focus would evoke an increase in the effects evoked by only one vibratory focus. The present study investigated whether WBV exposure during 10 repetitions of a handgrip dynamometer while standing on a WBV platform. Methods: Twenty-eight recreationally active university students completed 3 different test conditions, in random order: 1) grip dynamometer exercise with superimposed WBV and contralateral arm vibration (WBV+AV); 2) superimposed arm vibration only (AV); 3) grip dynamometer exercise without vibration (Control). Results: The hand grip strength was slightly higher in the WBV condition as compared to the Control and AV conditions (1.1% and 3.6%, p>0.05, respectively). A main effect of the EMGrms of extensor

digitorum muscle (ED) was observed indicating that the WBV+AV condition produced a lower co-activation of ED during a flexor digital task than the Control and AV ($p<0.05$) conditions. Conclusion: The application of WBV+AV may acutely increase muscle coordination and decreases the coactivation of ED. Furthermore, the muscle EMGrms showed increases in activation near the vibratory focus in both upper- and lower-body.

V. Metodología

a. Diseño experimental

El presente estudio investigó si la exposición a un estímulo de WBV durante 10 repeticiones de presión manual con dinamómetro mientras se está en bipedestación en la plataforma vibratoria bajo 3 condiciones diferentes, aleatorizadas, beneficiarían el rendimiento muscular (Figura 9). Se realizaron tres condiciones diferentes: 1) dinamometría manual con WBV y vibración del brazo contralateral (WBV+AV); 2) dinamometría manual con vibración del brazo contralateral (AV); 3) dinamometría manual sin vibración alguna (Control). Con el objetivo de evaluar las diferencias entre condiciones se realizaron análisis estadístico.

b. Participantes

Veintiocho hombres estudiantes y activos participaron en este estudio. Los valores medios (±DE) de los participantes para edad, talla y masa corporal fueron 22±1.6 años de edad, 178.7±6.8 cm y 74.6±9 kg, respectivamente. Los participantes eran físicamente activos pero ninguno comenzó un programa de ejercicio sistemático al menos 2 meses antes del comienzo del estudio. Todos los participantes estaban acostumbrados al ejercicio isométrico y al entrenamiento hasta el fallo muscular. Los criterios de exclusión fueron padecer diabetes, epilepsia, piedras en la vesícula, piedras en el riñón, enfermedades cardiovasculares, prótesis articulares, trombosis reciente, y problemas musculoesqueléticos. Para el test, se definió la dominancia manual de los participantes por su preferencia para la escritura. Se informó a los participantes de los procedimientos y de los riesgos potenciales de la participación en el estudio, y se las facilitó un consentimiento escrito. Una semana antes de las sesiones de registro, se realizaron dos sesiones de familiarización. El proyecto de investigación se llevó a cabo de acuerdo con la declaración de Helsinki.

c. Protocolo

Los participantes realizaron tres series sobre la plataforma vibratoria de forma aleatoria, por lo que todos los participantes estuvieron expuestos a las tres condiciones (WBV+AV, AV,

Control). El protocolo experimental comenzaba con la colocación de los electrodos, seguido por un calentamiento estandarizado que consistió en 2 min de trote despacio, 5 ejercicios de calentamiento dinámico, 10 repeticiones de cada ejercicio (caminar con cuatro apoyos, talones al glúteo, rodilla al pecho, sentadillas y zancadas laterales), y 5 repeticiones máximas de prensión manual. Fueron realizadas 10 repeticiones máximas de prensión manual utilizando un dinamómetro manual (Grip Strength Dynamometer T.K.K.5401; Takei Scientific Instruments Co., Ltd, Niigata, Japan) en cada serie. Entre cada serie hubo 10 min de recuperación. Cada repetición tuvo una duración de 2 s de contracción y 2 s de recuperación.

Los participantes se colocaron sobre la plataforma vibratoria en bipedestación en línea de pie-cadera-hombro con posición de semi-sentadilla con 30º de flexión de rodilla (considerando 0º la posición anatómica) (Figura 9).la colocación de los participantes se comprobó con un goniómetro. Cuando se añadía la flexión de codo isométrica, los participantes sostenían las cintas de agarre de la plataforma de vibraciones (utilizados para transferir la vibración a los miembros superiores), con una flexión de 90º de codo. Se solicitó a los participantes la realización de contracción máxima de bíceps utilizando la cinta de transmisión a la vez que se realizaba presión manual sobre el dinamómetro. Los ángulos articulares se monitorizaron durante cada repetición con *feedback* verbal por parte del investigador. Durante todas las condiciones, lo participantes calzaron el mismo calzado deportivo para estandarizar el estímulo vibratorio recibido.

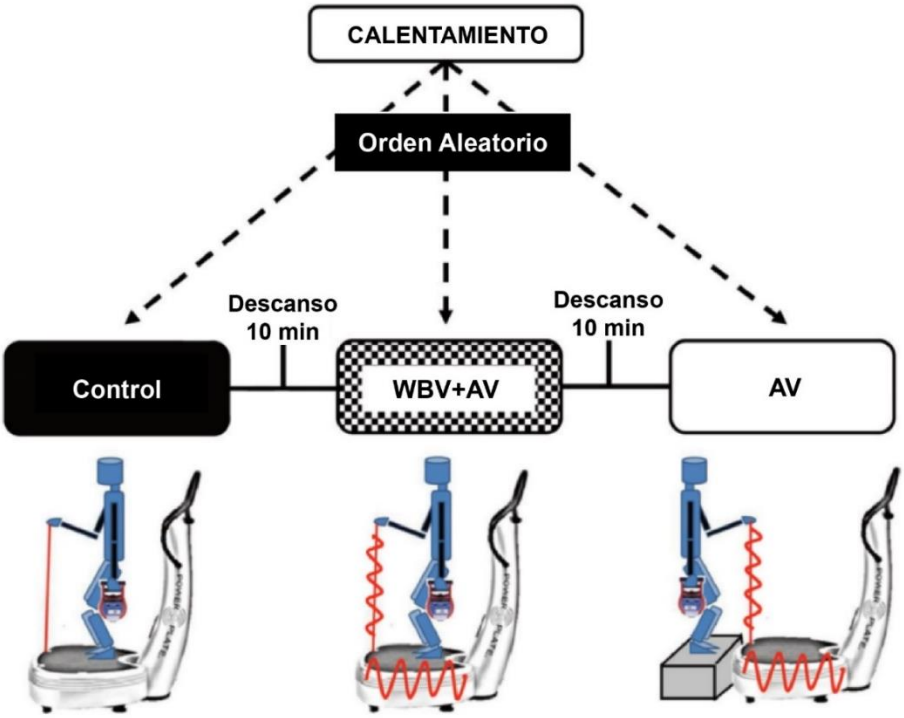


Figura 9. Diseño experimental estudio II.

d. Equipo vibratorio

La estimulación vibratoria se aplicó con una plataforma comercial (Pro5 Power Plate, Power Plate International Ltd., London, UK). La aceleración de la oscilación vertical sinusoidal (eje z) se midió utilizando un acelerómetro uni-axial de acuerdo con ISO2954 (Vibration meter VT-6360, Hong Kong, China). Los parámetros de la plataforma vibratoria fueron 50 Hz de frecuencia con un desplazamiento pico a pico de 2.51 mm (Alta). La medición de la aceleración fue 100.6±0.24 $m \cdot s^{-2}$.

e. Actividad electromiográfica superficial (EMG)

Se registró utilizando EMG (32, 105, 106) la actividad muscular del flexor radial de los dedos (FR), extensor digital (ED), bíceps braquial contralateral (BB) y gastrocnemio medial (GM).antes de la colocación de los electrodos, se afeitó y limpió la zona con alcohol isopropílico para reducir la impedancia de la piel. Se colocaron los electrodos sobre la mitad del vientre muscular, de forma paralela a la dirección de las fibras musculares de acuerdo con las recomendaciones del proyecto SENIAM (Surface ElectroMyo-Graphy for the Non-Invasive Assessment of Muscles) (104). Para el registro de las señales crudas mioeléctricas se utilizó la técnica de doble diferencial. Los electrodos estaban conectados a un convertidor de 16-bit AD (TrigoTMWireless System, Delsys Inc., Boston, MA, USA). Se amplificaron las señales crudas de EMG junto a los electrodos (ancho de banda de la señal de 20 – 450 Hz), muestreo a 4000 Hz, y fueron almacenadas en un ordenador portátil. El análisis de los datos de EMG se realizó mediante un programa informático (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, Massachusetts, USA). Se obtuvieron las medias de los datos de EMG mediante la raíz cuadrática media (rms), con el objetivo de obtener la amplitud media de la señal de EMG, y se seleccionó el valor máximo de cada repetición. Además, se realizó la mediana de la frecuencia (MDF) para obtener la frecuencia media. Se registró la EMG durante las 10 repeticiones isométricas de cada serie.

f. Análisis estadístico

Se analizaron los datos utilizando PASW/SPSS Statistics 20 (SPSS Inc, Chicago, IL), el nivel de significación se situó en P≤0.05. Los valores se presentaron como media error ± desviación estándar (SE). Todas las mediciones estaban distribuidas de forma normal, de acuerdo con el test Kolmogorov-Smirnov. El método Green-house-Geisser se utilizó para medir la esfericidad. Las variables dependientes se evaluaron con 1- vía de medidas repetidas con análisis de varianza (ANOVA). A los valores- F significativos obtenidos se les aplicó comparación por pares de Bonferroni post hoc. Se tuvo en cuenta el tamaño del efecto estadístico, η^2, para determinar la magnitud del efecto independientemente del tamaño de la muestra.

VI. Resultados

a. Fuerza isométrica de presión manual.

La fuerza de presión manual fue ligeramente superior en la condición WBV en comparación con las condiciones Control y AV (1.1% y 3.6%, respectivamente); sin embargo, no se observó una diferencia significativa ($p>0.05$; $\eta^2=0.048$) (Figura 10a). La fuerza máxima isométrica durante la décima repetición fue significativamente menor que en la sexta repetición ($p<0.001$; $\eta^2=0.739$), para las tres condiciones (Figura 10b). Se observó un efecto significativo en la interacción de condición y repetición

($p=0.047$; $\eta^2=0.057$) en la octava repetición entre las condiciones WBV+AV y AV, con mayores valores para la condición WBV+AV (Figura 10b).

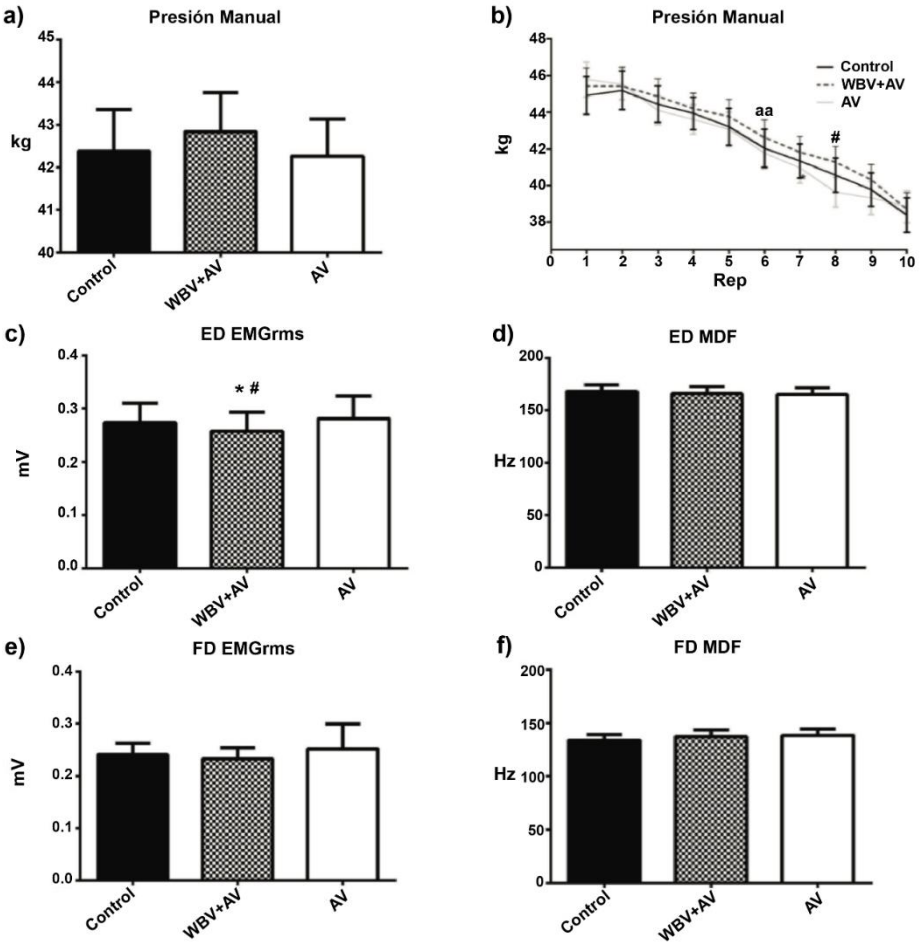


Figura 10. Resultados de fuerza de presión manual y EMG. WBV+AV, vibración de cuerpo completo y vibración de brazo, AV, vibración de brazo, ED, extensor de los dedos, EMGrms, raíz cuadrática media, MDF, frecuencia mediana. aa Disminución significativa de la repetición 6 en las tres condiciones ($p<0.001$). *Diferencia de condición Control ($p<0.05$). # Diferencia de condición AV ($p<0.05$).

b. Actividad muscular del extensor y flexor de los dedos

Se observó principalmente un efecto del ED EMGrms indicando que la condición WBV+AV producía una menor coactivación del extensor de los dedos durante una tarea principalmente realizada por el flexor de los dedos en comparación con las condiciones Control y AV ($p<0.05$; $\eta^2=0.111$). No se encontraron diferencias significativas en el registro de EMGrms de ED para las condiciones Control y AV (Figura 10c). La Tabla 5 (ED) y la Tabla 6 (FD) muestran el resumen de los efectos de repetición además de los principales efectos analizados con ANOVA para las variables dependientes de cada una de las 3 condiciones diferentes.

Tabla 5. Raíz cuadrática media (EMGrms) y frecuencia mediana (MDF) y músculo extensor digital de la mano dominante, durante las 3 condiciones, 10 repeticiones de cada condición.

	Músculo Extensor Digital					
	EMGrms (mV)			MDF (Hz)		
	Control	WBV+AV	AV	Control	WBV+AV	AV
Rep 1**	0.278±0.179	0.271±0.192	0.298±0.217	181.1±7.4	182.8±7.5	179.9±5.7
Rep 2##	0.273±0.195	0.264±0.209	0.287±0.233	175.2±6.9	172.1±7.1	168.6±6.3
Rep 3	0.283±0.200	0.265±0.201	0.263±0.227	170.0±6.6	174.5±7.5	162.3±6.1
Rep 4	0.273±0.211	0.246±0.200	0.289±0.242	172.1±6.3	162.8±6.7	162.9±6.5
Rep 5	0.295±0.220	0.251±0.195	0.286±0.236	163.8±6.7	165.1±6.6	163.9±6.8
Rep 6	0.272±0.207	0.247±0.195	0.286±0.228	167.3±6.5	162.5±6.3	159.9±7.4
Rep 7	0.286±0.225	0.246±0.183	0.273±0.237	164.0±6.1	160.9±6.5	160.3±6.1
Rep 8	0.255±0.191	0.241±0.165	0.258±0.215	163.1±6.1	160.8±6.8	163.1±6.2
Rep 9	0.256±0.179	0.238±0.186	0.264±0.214	160.8±6.4	158.3±7.6	167.9±6.2
Rep 10	0.253±0.165	0.236±0.179	0.279±0.209	163.1±6.3	158.8±7.6	162.5±6.1

***MDF diferencia estadística de Rep. 5-10 ($p<0.001$);## MDF diferencia estadística de Rep. 8-10 ($p<0.01$).*

Tabla 6. Raíz cuadrática media (EMGrms) y frecuencia mediana (MDF) y músculo flexor digital de la mano dominante, durante las 3 condiciones, 10 repeticiones de cada condición.

	Músculo Flexor Digital					
	EMGrms (mV)			MDF (Hz)		
	Control	WBV+AV	AV	Control	WBV+AV	AV
Rep 1**	0.213±0.017	0.211±0.018	0.233±0.027	151.0±4.8	154.5±7.5	157.9±7.0
Rep 2##	0.241±0.022	0.227±0.019	0.250±0.025	146.3±5.6	143.7±5.9	148.0±6.0
Rep 3	0.243±0.021	0.233±0.020	0.247±0.022	140.0±4.6	147.9±6.3	144.7±5.7
Rep 4	0.251±0.024	0.226±0.018	0.256±0.026	139.6±7.1	140.1±6.1	138.5±5.7
Rep 5	0.244±0.023	0.245±0.024	0.255±0.027	131.7±4.7	132.7±5.4	136.0±6.8
Rep 6	0.246±0.022	0.233±0.021	0.263±0.029	128.2±4.9	131.4±6.2	137.6±5.4
Rep 7	0.248±0.022	0.242±0.019	0.277±0.029	131.7±5.5	137.7±7.9	133.2±5.5
Rep 8	0.247±0.025	0.242±0.023	0.242±0.026	122.6±5.1	128.9±6.6	128.7±6.4
Rep 9	0.244±0.023	0.236±0.022	0.262±0.029	122.1±5.0	124.4±6.4	131.6±6.6
Rep 10	0.229±0.023	0.230±0.023	0.236±0.024	124.3±5.6	131.5±7.2	128.4±6.4

***MDF diferencia estadística de Rep. 2-10 ($p<0.001$);[##] MDF diferencia estadística de Rep. 9.*

c. Actividad muscular del bíceps braquial y el gastrocnemio medial

Los registros de EMGrms del músculo bíceps braquial durante las condiciones WBV y AV fueron significativamente mayores ($p<0.05$; $\eta^2=0.078$) que la condición Control (Figura 11a). Se encontró un efecto similar con MDF, observándose un efecto condición entre la condición Control y las condiciones WBV+AV y AV ($p<0.001$; $\eta^2=0.521$) indicando que la vibración del brazo produce una disminución en la frecuencia de la activación muscular en la musculatura cercana a la aplicación de la vibración (Figura 11b). La condición WBV+AV mostró un aumento significativo estadísticamente en la EMGrms de los GM ($p<0.001$; $\eta^2=0.596$) comparado con la condición Control y AV, indicando que la musculatura cercana al estímulo vibratorio experimenta un

aumento en la amplitud de la activación muscular (Figura 11c). Las comparaciones post hoc de los valores de EMGrms y MDF durante cada repetición se muestran en la Tabla 7 (BB) y Tabla 8 (GM)

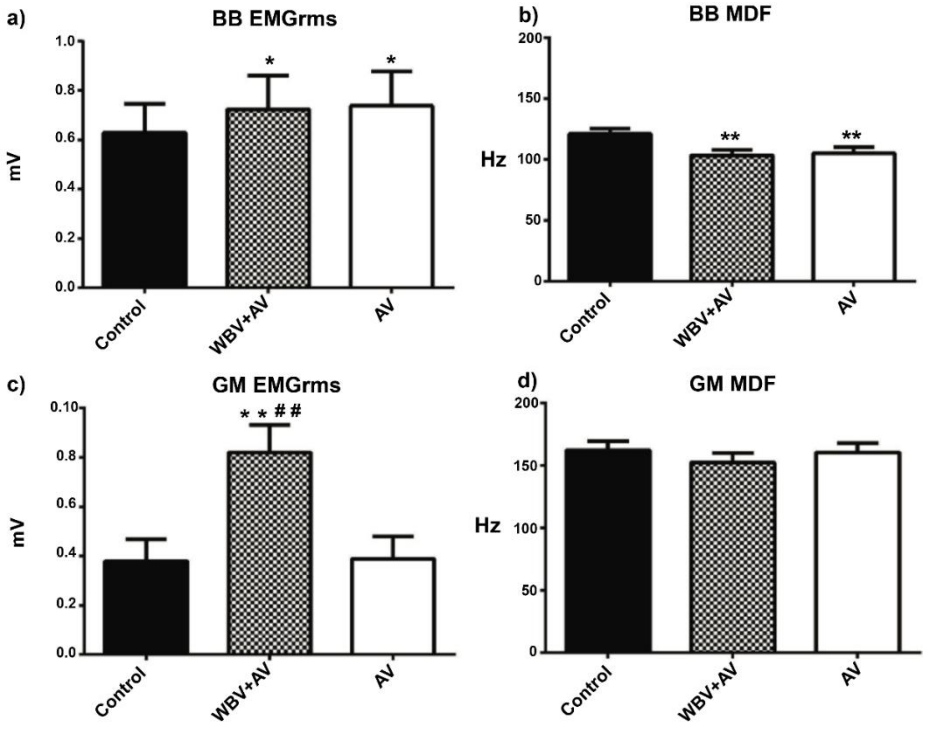


Figura 11. EMG de los músculos cercanos al foco vibratorio. WBV+AV, vibración de cuerpo completo y vibración de brazo, AV, vibración de brazo, BB, bíceps braquial, GM, gastrocnemio medial; EMGrms, raíz cuadrática media, MDF, frecuencia mediana. * Diferencias de condición Control ($p<0.05$). **Diferencia de condición Control ($p<0.001$). ## Diferencia de condición Control y AV, respectivamente ($p<0.001$).

Tabla 7. Raíz cuadrática media (EMGrms) y frecuencia mediana (MDF) y músculo bíceps braquial de la mano dominante, durante las 3 condiciones, 10 repeticiones de cada condición.

	Músculo Biceps Braquial					
	EMGrms (mV)			MDF (Hz)		
	Control	WBV+AV	AV	Control	WBV+AV	AV
Rep 1**	0.613±0.076	0.650±0.090	0.725±0.088	126.7±4.4	114.8±4.9	112.2±5.5
Rep 2	0.640±0.096	0.742±0.116	0.766±0.095	127.4±4.7	104.7±5.1	107.2±5.6
Rep 3	0.687±0.097	0.754±0.108	0.786±0.100	123.9±4.8	103.2±5.1	106.8±5.7
Rep 4	0.625±0.082	0.754±0.104	0.781±0.103	121.2±4.9	104.3±4.3	106.0±5.6
Rep 5	0.604±0.083	0.794±0.113	0.751±0.093	120.6±4.4	100.2±4.1	104.1±5.7
Rep 6##	0.697±0.095	0.724±0.097	0.782±0.103	119.3±4.6	101.5±4.8	101.5±5.1
Rep 7	0.633±0.086	0.722±0.103	0.714±0.092	119.2±4.6	101.7±4.2	103.2±5.2
Rep 8	0.612±0.080	0.727±0.088	0.724±0.082	119.1±4.6	101.3±4.9	103.8±5.0
Rep 9	0.602±0.082	0.681±0.091	0.681±0.087	117.3±5.0	101.1±4.5	102.3±4.8
Rep 10	0.565±0.087	0.688±0.084	0.667±0.093	116.0±3.8	99.7±4.9	104.0±4.6

***MDF diferencia estadística de Rep. 5-10 (p<0.001);## EMGrms diferencia estadística de Rep. 9 (p<0.001).*

Tabla 8. Raíz cuadrática media (EMGrms) y frecuencia mediana (MDF) y músculo gastrocnemio medial de la mano dominante, durante las 3 condiciones, 10 repeticiones de cada condición.

	Músculo Grastrocnemio Medial					
	EMGrms (mV)			MDF (Hz)		
	Control	WBV+AV	AV	Control	WBV+AV	AV
Rep 1	0.029±0.005	0.070±0.011	0.027±0.005	170.1±7.4	148.5±6.8	161.6±6.7
Rep 2	0.032±0.006	0.078±0.011	0.032±0.006	166.4±7.4	154.1±6.7	161.3±6.3
Rep 3	0.033±0.006	0.076±0.010	0.032±0.006	164.5±8.3	154.1±7.6	163.5±7.3
Rep 4	0.036±0.008	0.078±0.009	0.043±0.009	156.1±6.3	158.6±7.3	163.8±7.0
Rep 5	0.036±0.009	0.081±0.011	0.037±0.008	159.7±7.0	149.1±7.8	157.0±7.1
Rep 6	0.044±0.012	0.078±0.009	0.063±0.023	166.4±8.0	146.8±7.0	156.0±8.1
Rep 7	0.038±0.008	0.088±0.010	0.035±0.007	166.7±7.2	150.6±8.1	156.5±7.1
Rep 8	0.039±0.007	0.092±0.015	0.038±0.009	161.8±7.7	157.9±8.7	163.9±9.6
Rep 9	0.037±0.009	0.091±0.013	0.042±0.008	154.0±7.3	153.8±8.0	162.3±8.6
Rep 10	0.057±0.021	0.092±0.016	0.041±0.008	157.8±8.0	152.0±7.6	160.4±6.8

III

8. Artículo III

I. Título

El ejercicio de *battling rope* con la aplicación de forma sincrónica de vibraciones de cuerpo completo aumenta la actividad musculoesquelética.

II. Title

The addition of synchronous whole-body vibration to battling rope exercise increases skeletal muscle activity.

III. Resumen

Objetivo: Evaluar los efectos sobre el rendimiento en la actividad muscular de la musculatura de la pierna, tronco y miembros superiores del ejercicio de *battling rope* con y sin la adicción de WBV. Metodología: Veintiocho alumnos activos realizaron 6 condiciones separadas de 20 s de ondulaciones de *battling rope:* 1) movimiento alterno de brazos sin WBV –Alt_NoWBV; 2) movimiento alterno de brazos con WBV de 30 Hz y baja amplitud –Alt_30 Hz-L; 3) movimiento alterno de brazos con WBV de 50 Hz y alta amplitud –Alt_50 Hz-H; 4) movimiento simultáneo de brazos sin WBV –Double_NoWBV; 5) movimiento simultáneo de brazos con WBV de 30 Hz y baja amplitud –Double_30 Hz-L; 6) movimiento simultáneo de brazos con WBV de 50 Hz y alta amplitud –Double_50 Hz-H. Se registró la EMG de los músculos gastrocnemio medial (GM), vasto medial oblicuo (VMO), vasto

lateral (VL), recto abdominal (RA), multífido (MF), bíceps braquial (BB), y tríceps braquial (TB). Resultados: El movimiento doble de brazos produjo mayor actividad muscular ($p<0.05$) en los músculos VMO, VL, RA y MF mientras que GM se activó más en EMG durante el movimiento alterno de brazos. Las condiciones de WBV a 50 Hz aumentó la EMG en todos los músculos registrados frente a las condiciones NoWBV y 30 Hz. Conclusión: Estos resultados son los primeros que demostraron que el estímulo recibido del ejercicio de *battling rope* puede verse incrementado con la exposición a un estímulo WBV aplicado mediante una plataforma vibratoria.

IV. Abstract

Objectives: To evaluate the effects of performing battling rope exercise with and without the addition of WBV on muscle activity of the leg, trunk, and upper body. Methods: Twenty-eight recreationally active university students completed 20-s of battling rope undulation for 6 separate conditions: 1) alternating arm motion no WBV -Alt_NoWBV; 2) alternating arm motion 30 Hz low amplitude WBV -Alt_30 Hz-L; 3) alternating arm motion 50 Hz high amplitude -Alt_50 Hz-H; 4) double arm motion no WBV -Double_NoWBV; 5) double arm motion 30Hz low amplitude WBV -Double_30Hz-L; 6) double arm motion 50 `Hz high amplitude -Double_50 Hz-H. EMG was measured for the gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis

(VL), rectus abdominis (RA), multifidus (MF), biceps brachii (BB), and triceps brachii (TB) muscles. Results: The double arm motion during undulation resulted in greater ($p<0.05$) muscle activity in the VMO, VL, RA, and MF muscles while the GM was more active during the alternating arm motion. WBV at 50Hz increased EMG in all muscles measured vs NoWBV and the 30 Hz condition. Conclusion: These results are the first to demonstrate that the exercise stimulus of performing battling rope exercise can be augmented by completing the exercise while being exposed to WBV from a ground-based platform.

V. Metodología

a. Diseño experimental

Con el objeto de investigar la activación muscular para las diferentes condiciones, se llevó a cabo un diseño experimental cruzado y aleatorizado (las condiciones se colocaron en una caja y fueron seleccionadas una a una por los participantes). Cada participante realizó tres sesiones en este estudio (2 sesiones de familiarización y 1 de registro). El protocolo experimental comenzaba con la colocación de los electrodos, seguido de un calentamiento estandarizado que consistió en 2 min de trote y 5 ejercicios de calentamiento dinámico (10 repeticiones de cada ejercicio: talones al glúteo, rodilla al pecho, sentadillas, zancadas laterales y caminar a 4 apoyos). Tras ello, cada participante realizaba series de 20 s de batido ondulatorio de *battling rope*

durante 6 condiciones seguidas de 5 min de recuperación (Figura 12). Todas las repeticiones se realizaron en una plataforma de WBV y las 6 condiciones diferentes (Figura 12) realizadas de forma aleatoria fueron: 1) Movimiento de brazos alterno sin WBV - Alt_NoWBV; 2) Movimiento de brazos alterno con 30Hz amplitud baja de WBV - Alt_30Hz-L; 3) Movimiento alterno de brazos con 50Hz amplitud alta de WBV – Alt_50Hz-H; 4) Movimiento simultaneo de brazos sin WBV – Doble_NoWBV; 5) Movimiento simultaneo de brazos con 30Hz amplitud baja de WBV - Doble_30Hz-L; 6) Movimiento simultaneo de brazos con 50Hz amplitud alta de WBV – Doble_50Hz-H.

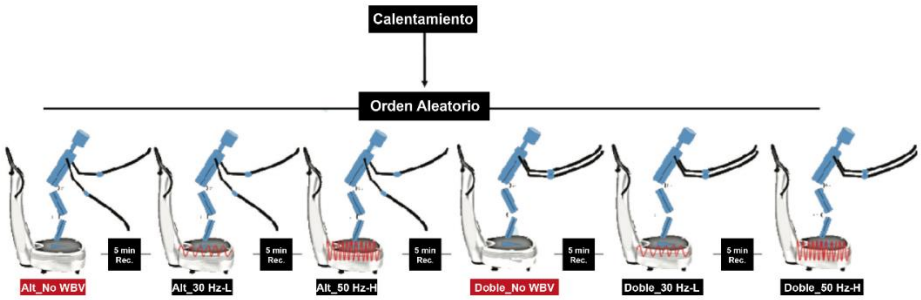


Figura 12. Diseño experimental estudio III.

b. Participantes

En el estudio participaron veintiocho estudiantes (5 mujeres; 23 hombres) (21.7±1.3 años de edad; 176.7±0.3 cm; 74.0±6.4 kg; media ± DE). Todos los participantes eras físicamente activos de forma recreativa pero ninguno comenzó un entrenamiento sistemático con al menos 2 meses de antelación a la recogida de

datos. Se excluyó a las personas que padecían epilepsia, piedras en la vesícula, piedras en el riñón, enfermedades neuromusculares o neurodegenerativas, infarto, enfermedades graves de corazón o tener una prótesis, bypass o válvula (3 en total, 1 mujer). Antes de la recolección de datos se informó a los participantes de los requerimientos asociados con la participación y se les suministró un consentimiento informado por escrito. Se solicitó a los participantes que mantuvieran sus hábitos de dieta, sueño y bebida durante el estudio (tanto en las sesiones de familiarización como en la sesión de registro). El proyecto de investigación se realizó de acuerdo a la Declaración de Helsinki y fue aprobado por el Gabinete de Revisión de Proyectos Humanos.

c. Ejercicio de battling rope

Los participantes utilizaron una cuerda de nylon de 15 m de longitud, 11.2 kg de peso y 3.8 cm de diámetro (O'Live Fitness, Aerobic & Fitness SL, Barcelona, Spain). La cuerda se ancló a la base de un poste, por lo que el participante sostenía 7.5 m de cuerda en cada mano. La posición de los participantes en la plataforma vibratoria era una posición atlética; misma anchura de los pies y hombros, rodillas en flexión de 30 con el tronco inclinado hacia adelante unos 45º (Figura 12). Se midieron estos ángulos mediante un goniómetro al inicio de la serie, y se solicitó a los participantes a que mantuvieran dicha posición durante toda la

serie. Los participantes sostenían los extremos de la cuerda con un agarre neutro, con los brazos rectos y relajados a cada lado.

Para el movimiento de brazos alterno, los participantes realizaban un movimiento de brazos de subida y bajada de ritmo asincrónico (alternativo) (ej. el brazo derecho comienza primero y mientras regresa a la posición inicial, el brazo izquierdo comienza el movimiento; Figura 12). Para el ejercicio de movimiento doble de brazos, los participantes movían ambos brazos arriba y debajo de forma sincrónica (al mismo tiempo) y de forma continua (Figura 12). Se solicitó a los participantes un movimiento de brazos lo más rápido posible, y además a que utilizaran el miembro inferior y el tronco lo mínimo posible, con el objetivo de que la ondulación partiera de la articulación del hombro al flexionarse cuando se eleva la cuerda y al extenderse cuando la cuerda impactaba contra el suelo. Se familiarizó a los participantes con que el pie no despegara de la plataforma en ningún momento, con la misma anchura de pies y hombros. Todos los participantes mantenían una flexión de 30º de rodilla durante el ejercicio.

d. Dispositivo vibratorio

El estímulo vibratorio fue aplicado mediante una plataforma vibratoria comercial (Power Plate® Next Generation pro 5, Power Plate North America, Northbrook, IL, USA) que producía oscilaciones sincrónicas (uniformes) en tren planos (32, 99). Se midió la aceleración de las oscilaciones verticales sinusoidales (eje

– z) utilizando un acelerómetro axial de acuerdo con ISO2954 (Vibration meter VT-6360, Hong Kong, China). Los parámetros de la plataforma vibratoria fueron una frecuencia de 50 Hz con un desplazamiento pico a pico de 2.51 mmm (High) o una frecuencia de 30Hz con un desplazamiento pico a pico de 1.15mm (Low). Las aceleraciones medidas fueron 100.6 ± 0.24 $m \cdot s^{-2}$ (a 50Hz) y 20.44 ± 0.34 $m \cdot s^{-2}$ (a 30Hz). Los participantes calzaban el mismo calzado deportivo durante todas las condiciones, con el objetivo de estandarizar la absorción de la vibración por parte del calzado (32).

e. Actividad electromiográfica superficial (EMG)

Se registró la actividad muscular mediante EMG (6, 31, 32, 102, 103) del gastrocnemio medial (GM), vasto medial oblicuo (VMO), vasto lateral (VL), rectoabdominal (RA), músculo multífico (MF), bíceps braquial (BB), y tríceps braquial (TB) de la extremidad dominante. Antes de la colocación de los electrodos, el área fue rasurada y limpiada con alcohol isopropílico para reducir la impedancia de la piel. Los electrodos se colocaron sobre la zona media del vientre muscular, de forma paralela a la dirección de las fibras, de acuerdo a las recomendaciones del proyecto de SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles), se utilizó adhesivo de doble cara (104).

Para detectar las señales mioeléctricas en crudo, se utilizó la técnica del doble diferencial. Los electrodos estaban conectados a un convertidor de 16-bit AD (TrigoTM Wireless System, Delsys

Inc., Boston, MA, USA). Se pre-amplificaron las señales de EMG en crudo junto a los electrodos (anchura de banda de 20-450 Hz) y muestreo de 4000Hz y se almacenaron en un ordenador portátil. El análisis de los datos de EMG se realizó utilizando un programa específico (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, MA, USA). Se obtuvieron las medias de los datos de EMG mediante raíz cuadrática media (EMGrms) con el objetivo de obtener la amplitud de la señal de EMG. EMGrms se calculó de forma conjunta para la fase concéntrica y excéntrica. Además, para obtener la frecuencia media, se obtuvieron las medias mediante la frecuencia mediana (EMGmdf), la cual es una medida válida que se asocia con la fatiga muscular (107). Para el análisis de datos se utilizaron únicamente 15 s de cada condición (de 2.5 s a 17.5 s).

f. Movimiento de brazos

Se registró la frecuencia del movimiento de brazos utilizando un acelerómetro tri-axial (TrigoTM Wireless System, Delsys Inc., Boston, MA, USA) anclado a la muñeca del brazo dominante. La configuración del acelerómetro permitía la sincronización con la EMG. Se amplificaron las señales en crudo del acelerómetro a 148Hz y se almacenaban en un ordenador portátil, el análisis de datos se realizó utilizando un programa específico (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, MA, USA). Se registraron las frecuencias de oscilación de brazos durante 20 s

para cada una de las condiciones en el eje-y (anterior/posterior), eje z (superior/inferior), y eje-x (derecha/izquierda).

g. Frecuencia cardiaca

Se registró la frecuencia cardiaca media y máxima (latidos por minuto) latido a latido con un sistema de monitorización de la frecuencia cardiaca (Polar RS400, Polar Electro Oy, Kempele, Finland).

h. Análisis estadístico

Se analizaron los datos utilizando PASW/SPSS Stadistics 20.0 (SPSS Inc, Chicago, IL, USA). Se comprobó y confirmó la normalidad de los datos con el test Shapiro-Wilk. Las variables dependientes (EMG de cada músculo, movimiento de los brazos en los 3 ejes, y frecuencia cardiaca), se evaluaron mediante análisis de variación para medidas repetidas (ANOVA) para movimiento x condición. En los casos en los que el valor-F resultaba significativo, se aplicaba el procedimiento de comparación por pares Bonferroni post hoc. El nivel de significación se estableció en $p \leq 0.05$. Durante las sesiones de familiarización, se calcularon los coeficientes de correlación intraclase (ICC) para determinar la fiabilidad test-retest para la frecuencia cardiaca y el movimiento de brazos en los 3 ejes. Los ICC fueron mayores de 0.92 lo cual indica un nivel de

reproducibilidad alto en el registro de las variables dependientes. Los valores se expresaron en media±DE y el tamaño de los efectos se registró con Eta cuadrado parciales (η^2) para determinar la magnitud de los efectos independientemente del tamaño de la muestra.

VI. Resultados

a. Músculo gastrocnemio medial (GM)

Se encontró un efecto de la interacción movimiento x condición para el GM ($p=0.001$; $\eta^2=0.358$; ver Figura 13a). Se observó un principal efecto respecto al tipo de movimiento, lo cual indica un aumento significativo de la actividad de EMGrms del GM durante el movimiento alternativo en comparación con el movimiento simultaneo de brazos ($p=0.001$; $\eta^2=0.461$). Se encontró un principal efecto respecto a la condición, indicando que la actividad EMGrms del GM aumentaba significativamente durante la condición 50Hz-H en comparación con las condiciones NoWBV y 30Hz-L ($p=0.001$; $\eta^2=0.680$). En el caso de EMGmdf del GM (Tabla 9), el estímulo fue menor durante el movimiento alterno de brazos y 30Hz-L ($p<0.05$) en comparación con 50Hz-H y NoWBV. También fue menor en 50Hz-H que en NoWBV. No hubo diferencias para el movimiento simultáneo de brazos.

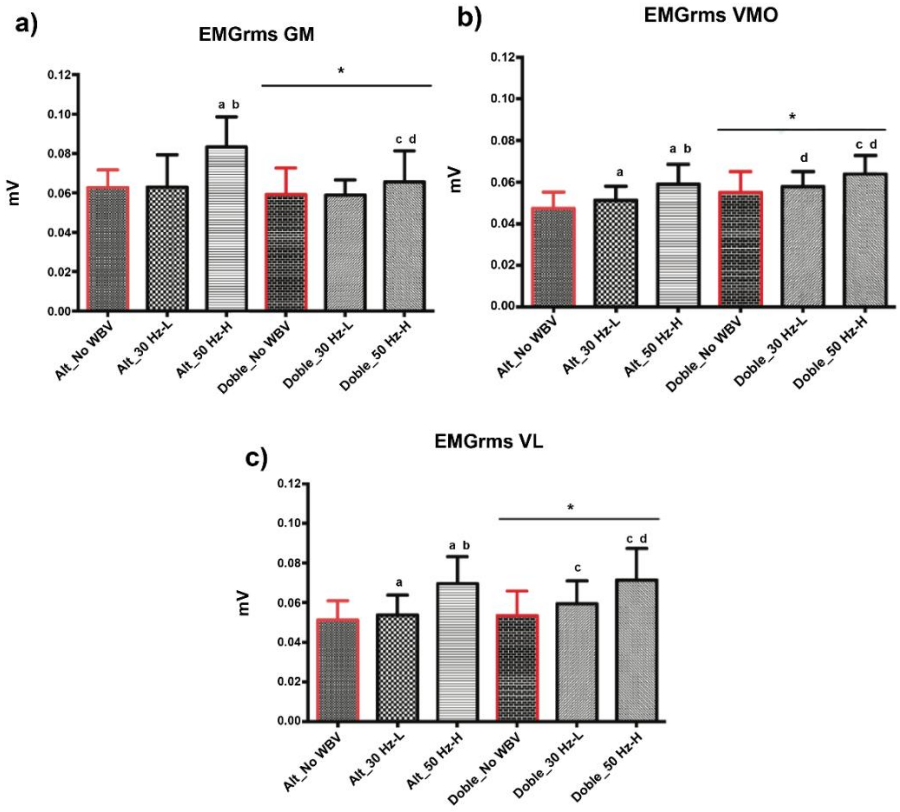


Figura 13. Actividad EMGrms de las (a) gastrocnemio medial (GM), (b) vasto medial oblicuo (VMO), y (c) vasto lateral (VL), durante las 6 condiciones experimentales. a Diferencia significativa de condición Alt_No ($p<0.05$). b Diferencia significativa de condición Alt_30 Hz-L ($p<0.05$). c Diferencia significativa de condición Doble_No ($p<0.05$). d Diferencia significativa de condición Doble _30 Hz-L ($p<0.05$). * Diferencia de movimiento alterno para la misma condición ($p<0.01$) ($n=28$).

b. Músculos vasto medial oblicuo (VMO) y vasto lateral (VL)

Se encontró un efecto en la interacción movimiento x condición para VMO (p=0.030; η^2=0.122; ver Figura 13b) y VL (p=0.005; η^2=0.176; ver Figura 13c). Se observó un principal efecto para el tipo de movimiento indicando que EMGrms aumenta significativamente para VMO (p=0.001; η^2=0.649) y VL (p=0.002; η^2=0.294) durante el movimiento simultáneo de brazos en comparación con el movimiento alterno. Se obtuvo un principal efecto respecto a la condición, lo cual indicaba que EMGrms aumentaba para VMO (p=0.001; η^2=0.827) y VL (p=0.001; η^2=0.805) durante 50Hz-H en comparación con NoWBV y 30Hz-L, también fue mayor para 30Hz-L en comparación con NoWBV (p<0.001).

Respecto a EMGmdf en el músculo VMO (Tabla 9), el movimiento alterno de brazos durante 30Hz-L produjo menor EMGmdf en comparación con NoWBV. Durante el movimiento simultáneo de brazos, la condición de 30Hz-L fue menor que la condición NoWBV. Para el VL, 50Hz-H fue menor (p<0.05) en comparación con NoWBV para ambos movimientos de brazo alterno y simultaneo.

Tabla 9. Frecuencia mediana de la actividad EMG (Hz) de los músculos gastrocnemio medial (GM), vasto medial oblicuo (VMO), vasto lateral (VL), recto abdominal (RA), multífidos (MF), bíceps braquial (BB), y tríceps braquial (TB) durante las 6 condiciones experimentales.

	GM	VMO	VL	RA	MF	BB	TB
Alt_No WBV	106.8±32.1	78.6±17.1	80.8±14.3	48.9±15.6	57.4±10.6	68.9±10.3	70.1±11.7
Alt_30 Hz-L	100.0±29.2	74.8ª±18.9	76.3±15.4	47.9±15.1	58.3±11.1	68.0±10.7	69.3±12.9
Alt_50 Hz-H	103.4±31.6	75.5±16.7	73.8ª±16.2	48.3±14.0	60.0±8.8	67.5±11.0	69.8±11.8
Doble_No WBV	100.0**±32.1	79.6±16.5	79.0±11.9	48.9±10.9	63.9**±13.5	68.4±13.7	66.9*±15.4
Doble_30 Hz-L	95.7**±28.2	75.7ᵇ±19.3	74.1±13.4	46.5±11.5	61.2**±13.5	67.1±12.1	66.9*±15.9
Doble_50 Hz-H	98.2**±28.4	77.3±17.2	72.7ᵇ±13.6	45.9±10.1	62.3**±12.0	65.8±12.4	68.3*±12.8

a *Diferencia significativa de la condición Alt_No (p<0.05).* ***b*** *Diferencia signifativa de movimiento Doble_No (p<0.05).* ***c*** *Diferencia significativa de la condición Doble_No WBV. *Diferencia de movimiento alterno para la misma condición (p<0.05). ** Diferencia de movimiento alterno para la misma condición (p<0.01) (n=28).*

c. Músculos recto abdominal (RA) y multífidos (MF)

Se detectó un efecto en la interacción de movimiento x condición para el RA (p=0.001; η^2=0.610; ver Figura 14a). Sin embargo, no se encontraron efectos significativos en la interacción movimiento x condición para el MF (p>0.05; η^2=0.003; ver Figura 14b). Se observó un efecto en relación al tipo de movimiento, indicando que existe un aumento significativo en EMGrms de RA (p=0.001; η^2=0.839) y MF (p=0.001; η^2=0.737) durante el movimiento simultaneo en comparación con el movimiento alterno de brazos. Se encontró un efecto condición, indicando que EMGrms de RA (p=0.001; η^2=0.600) y MF (p=0.001; η^2=0.354) aumentaba para la condición 50Hz-H en comparación con 30Hz-L, al igual que 30Hz-L en comparación con NoWBV (p<0.001).

No se encontraron diferencias en EMGmdf en el RA (Tabla 9). Para el músculo MF, la condición de movimiento alterno de brazos NoWBV fue menor que ambas condiciones WBV, también se encontró esta menor EMGmdf en 30Hz-L con respecto a 50Hz-H.

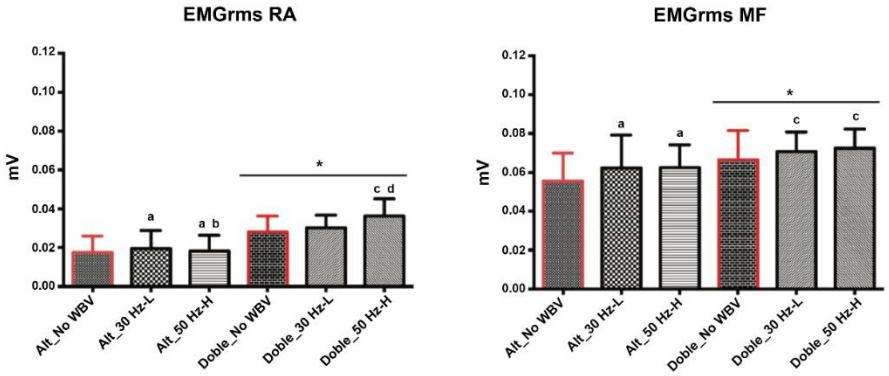


Figura 14. Actividad EMGrms de los músculos recto abdominal (RA), y multífidos (MF) durante las 6 condiciones experimentales. a Diferencia significativa de la condición Alt_No ($p<0.05$). c Diferencia significativa de la condición Doble_No ($p<0.05$). * Diferencia de movimiento alterno de la misma condición ($p<0.01$) (n=28).

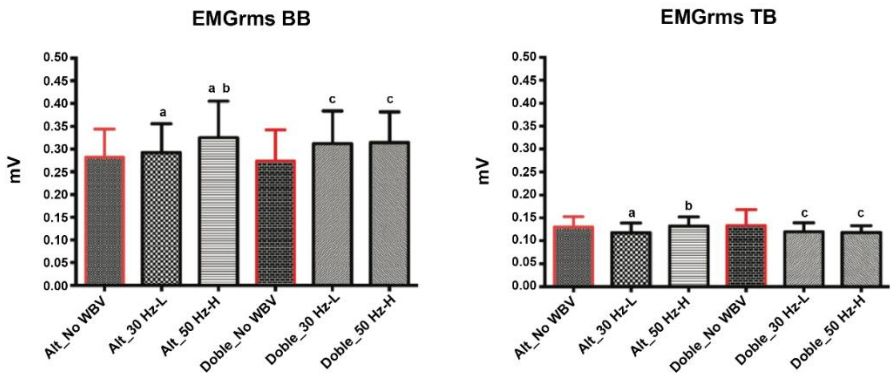


Figura 15. Actividad EMGrms de los músculos bíceps braquial (BB), y tríceps braquial (TB) durante las 6 condiciones experimentales. a Diferencia significativa de la condición Alt_No ($p<0.05$). b Diferencia significativa de la condición Alt_30 Hz-L ($p<0.05$). c Diferencia significativa de la condición Doble_No ($p<0.05$) (n=28).

d. Músculos bíceps braquial (BB) y tríceps braquial (TB)

Se observó un principal efecto en la interacción movimiento x condición para BB ($p=0.001$; $\eta 2=0.213$; ver Figura 15a) y TT ($p=0.001$; $\eta^2=0.287$; ver Figura 15b). No hubo diferencias significativas para el tipo de movimiento en el BB ($p>0.05$; $\eta^2=0.031$) ni en el TB ($p>0.05$; $\eta^2=0.001$). Se encontró un efecto condición, lo cual indica que hubo un aumento significativo de EMGrms para BB ($p=0.001$; $\eta^2=0.603$) y una disminución significativa para TB ($p=0.001$; $\eta^2=0.369$) para 50Hz-H en

comparación con 30Hz-L y NoWBV, al igual que para 30Hz-L comparado con NoWBV ($p<0.001$).

No hubo diferencias significativas en EMGmdf en el BB (Tabla 9). Para el TB, el movimiento simultáneo de brazos produjo menor EMGmdf ($p<0.05$) que el movimiento alterno para la misma condición.

e. Movimiento de brazos

No se encontraron efectos significativos para la interacción de movimiento x condición para la coordenada-y durante el ejercicio de *battling rope* ($p>0.05$; $\eta^2=0.038$; Figura 16b). Se encontró un efecto para el tipo de movimiento, indicando un aumento significativo en la frecuencia en el movimiento de brazos en la coordenada-x (anterior/posterior) para el movimiento simultáneo de brazos en comparación con el movimiento alterno ($p=0.001$; $\eta^2=0.465$). Se observó un efecto condición, que indicaba un aumento significativo en la frecuencia de movimiento de brazos en la coordenada-y para la condición 50Hz-H en comparación con NoWBV ($p=0.020$; $\eta^2=0.138$).

No se encontraron diferencias significativas para la interacción de movimiento x condición ($p>0.05$; $\eta^2=0.050$; Figura 16c). Se encontró un efecto movimiento, indicando un aumento significativo de la frecuencia del movimiento de brazos en la coordinada-z (superior e inferior) durante el movimiento simultáneo de brazos, en comparación con el movimiento alterno ($p=0.001$; $\eta^2=0.338$).

Respecto al efecto condición, se encontró un aumento significativo en la frecuencia del movimiento de brazos en la coordenada-z para 50Hz-H, en comparación con NoWBV ($p=0.020$; $\eta^2=0.132$).

No se detectó efecto en la interacción movimiento x condición para la coordenada-x ($p>0.05$; $\eta^2=0.034$; Figura 16d). Tampoco se encontró efecto movimiento ($p>0.05$; $\eta^2=0.028$) o condición ($p>0.05$; $\eta^2= 0.069$).

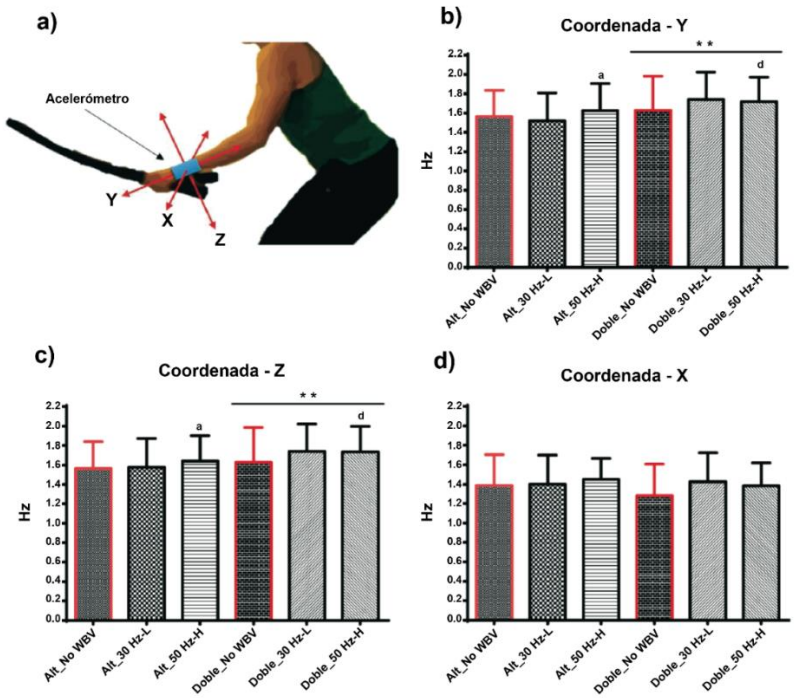


Figura 16. Frecuencia de movimiento de brazos (a) durante las 6 condiciones experimentales en el (b) coordenada-y, (c) coordenada-z, y (d) coordinada-x. a Diferencia significativa de la condición Alt_No WBV ($p<0.05$). c Diferencia significativa de la condición Doble_No WBV ($p<0.05$). * Diferencia del movimiento alterno para las mismas condiciones ($p<0.01$) ($n=28$).

f. Frecuencia cardiaca

No hubo diferencias significativas en la interacción de movimiento x condición para la frecuencia cardiaca media ($p>0.05$; $\eta^2=0.012$; Figura 17a), al igual que no se encontró un efecto significativo para el tipo de movimiento ($p>0.05$; $\eta^2=0.015$) o condición ($p>0.05$; $\eta^2=0.002$) frecuencia cardiaca media. No se encontraron diferencias significativas en la interacción de movimiento x condición para la frecuencia cardiaca máxima ($p>0.05$; $\eta^2=0.038$). Se observó un efecto movimiento indicando una menor frecuencia cardiaca máxima durante el movimiento simultáneo de brazos en comparación con el movimiento alterno ($p=0.048$; $\eta^2=0.137$). También se encontró un efecto condición, donde la frecuencia cardiaca máxima fue mayor para la condición 50Hz-H que para la condición NoWBV ($p=0.027$; $\eta^2=0.125$; Figura 17b).

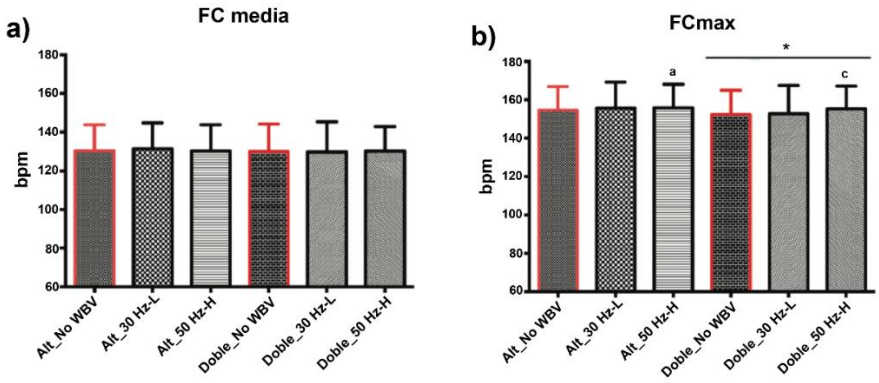


Figura 17. Latidos por minuto (BPM) de la frecuencia cardiaca media (a) y máxima (b).

IV

9. Artículo IV

I. Título

Efectos de las vibraciones de cuerpo completo aplicadas sobre la musculatura de las extremidades inferiores durante el ejercicio de press de banca declinado.

II. Title

Effects of whole-body vibration applied to lower extremity muscles during decline bench press exercise.

III. Resumen

Objetivo: Evaluar los efectos de WBV sobre la actividad musculoesquelética y la potencia de los miembros superiores durante un ejercicio de press banca declinado con diferentes cargas. Metodología: Participaron cuarenta y siete estudiantes activos. Cada uno realizó varias repeticiones de press de banca declinado sin y con WBV (50 Hz, 2.2 mm) aplicado durante un ejercicio de puente isquiosural, con diferentes cargas de 1-repetición máxima (1RM): 30%,50% y 70% 1RM. Se registró la actividad muscular mediante electrodos de electromiografía de los músculos tríceps braquial (TB), bíceps braquial (BB), pectoral mayor (PM), y bíceps femoral (BF); los parámetros cinemáticos se registraron mediante un encoder rotacional. Resultados: WBV aumentó la potencia pico (PP) durante la condición de 70% 1RM ($p<0.01$). La actividad muscular se vio aumentada con WBV en los

músculos TB y BF para todas las cargas ($p<0.05$). No hubo efectos de WBV sobre los músculos BB y PM. Conclusión: WBV aplicado mediante el ejercicio de puente isquiosural aumenta la actividad muscular del TB durante el ejercicio de press banca declinado, y este aumento contribuye al aumento de la potencia pico a cargas altas y un aumento de la aceleración pico a cargas bajas.

IV. Abstract

Objectives: To evaluate the effects of WBV on skeletal muscle activity and power performance of the upper body during decline bench press exercise at different loads. Methods: Forty-seven healthy young and active male students volunteered. Each performed dynamic decline bench press repetitions with and without WBV (50 Hz, 2.2 mm) applied through a hamstring bridge exercise at three different loads of their 1-repetition maximum (1RM): 30%, 50%, and 70% 1RM. Muscle activity of the triceps brachii (TB), biceps brachii (BB), pectoralis major (PM), and biceps femoris (BF) was measured with surface electromyography electrodes and kinetic parameters of the repetitions were measured with a rotary encoder. Results: WBV increased peak power (PP) output during the 70% 1RM condition ($p<0.01$). Muscle activity was increased with WBV in the TB and BF muscles at all loads ($p<0.05$). There were no effects of WBV on BB or PM muscles. Conclusion: WBV applied through a hamstring bridge exercise increases TB muscle activity during a decline bench press and this augmentation

contributes to an increased peak power at higher loads and increased peak acceleration at lower loads.

V. Metodología

a. Sujetos

Cuarenta y siete estudiantes, hombres, jóvenes y activos (21.6±1.6 años de edad; 176.0±5.7 cm; 71.9±8.6 kg; media±DE) participaron de forma voluntaria en el estudio. Los participantes eran activos recreacionalmente (con experiencia en el entrenamiento de fuerza), pero ninguno comenzó un programa de entrenamiento sistemático durante la recolección de daos o al menos en los dos meses previos al comienzo del estudio. Los criterios de exclusión fueron diabetes, epilepsia, piedras en la vesícula, piedras en el riñón, enfermedades cardiovasculares, prótesis articulares, trombosis reciente y problemas musculoesqueléticos. Antes de la recolección de los datos, se informó a los participantes de los requerimientos asociados a la participación y se les suministró un consentimiento informado. El proyecto de investigación se llevó a cabo de acuerdo con la declaración de Helsinki.

b. Diseño experimental

Este estudio investigó si el estímulo WBV aplicado durante un ejercicio de puente de isquiosurales (Figura 18) beneficiaría el rendimiento muscular en comparación con la condición control (CTRL) durante un ejercicio de press banca declinado (utilizando una Máquina Smith) y si diferentes cargas inducirían diferencias en el rendimiento neuromuscular y potencia. Se realizó el ejercicio dinámico de press banca declinado en seis condiciones: 1) baja carga, 30% de 1 repetición máxima (RM) sin WBV (CTRL-30); 2) baja carga, 30% 1RM con WBV (WBV-30); 3) media carga, 50% de 1 repetición máxima (RM) sin WBV (CTRL-50); 4) media carga, 50% 1RM con WBV (WBV-50); 5) alta carga, 70% de 1 repetición máxima (RM) sin WBV (CTRL-70); 6) alta carga, 70% 1RM con WBV (WBV-70).

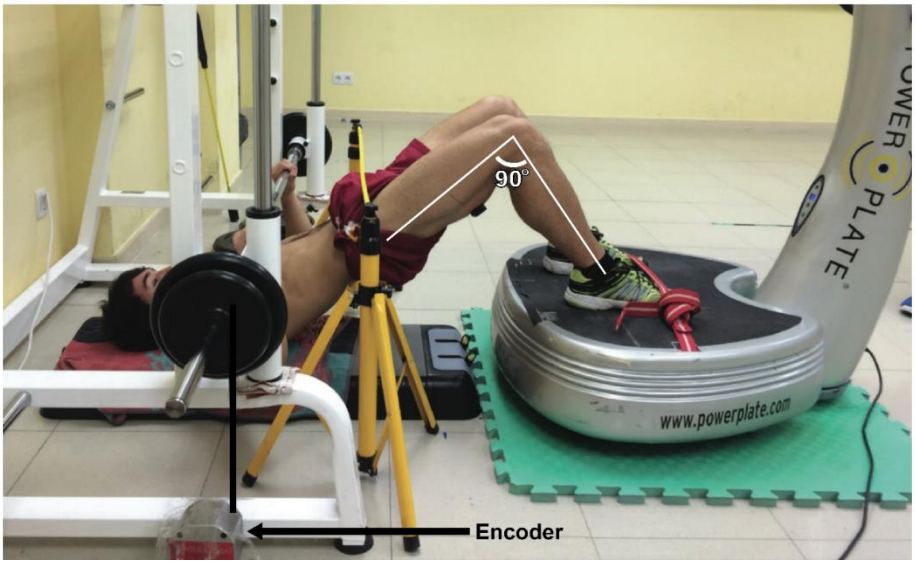


Figura 18. Diseño experimental estudio IV

c. Sesión de familiarización

Una semana antes de las sesiones de pruebas, los participantes asistieron a 2 sesiones de familiarización, donde la primera fue utilizada para aclimatar a los participantes con el protocolo del estudio y la segunda para determinar su 1 repetición máxima (RM) utilizando una máquina Smith (Telju, Toledo, España). En ambas sesiones los participantes realizaron un calentamiento estandarizado que consistió en 2 min de trote suave y 5 ejercicios de calentamiento dinámicos (10 repeticiones, sentadillas, zancadas laterales, caminar con cuatro apoyos y 2 series de 10 repeticiones de press de banca declinado con 20kg de carga). Tras el calentamiento, los participantes adoptaban la posición experimental (puente de isquiosurales con apoyo plano sobre la plataforma y manos en la barra; Figura 18) Para el propósito del estudio, 1-RM se define como la carga máxima que un participante puede levantar con buena técnica a lo largo de todo el rango de movimiento (la barra bajaba has tocar ligeramente el pecho, aproximadamente 3 cm por encima de la apófisis xifoides). La separación de las manos se ajustó para cada participante para que no fuera mayor de 1.5 la anchura biacromial y los pies se mantuvieron en contacto plano con la plataforma de WBV en el puente de isquiosurales durante cada repetición (Figura 18). Las repeticiones de 1-RM siguieron las líneas de la NSCA (108). En resumen, los participantes realizaron un calentamiento con carga baja (50% de 1-RM estimado) durante 8-10 repeticiones seguidas de 3 min de recuperación. El test comenzó con una carga del 70%

de 1-RM estimado, y la carga incrementaba en 5-10 kg has alcanzar 1-RM. Cada repetición estaba separada con 3 min de recuperación y el 1-RM se alcanzó con 5 intentos o menos para prevenir la fatiga.

d. Sesiones experimentales

Se colocó los electrodos de EMG (detallado a continuación) antes de realizar el calentamiento estandarizado (idéntico a la sesión de familiarización). Tras este calentamiento, los participantes realizaron una contracción máxima isométrica en la posición de press de banca para determinar la contracción máxima voluntaria (MVC) de todos los músculos. La posición experimental era adoptada por los participantes (Figura 18) para realizar las seis condiciones experimentales (WBV-30, Control-30, WBV-50, Control-50, WBV-70, y Control-70), mientras se realizaba un puente de isquiosurales con los pies en la plataforma de WBV. Todas las condiciones se realizaron en orden aleatorio. Se realizaron tres repeticiones explosivas máximas en las que se solicitó a los participantes la realización de las mismas lo más fuerte y rápido posible. Se utilizó una máquina Smith (Telju, Toledo, España) para realizar las repeticiones, las repeticiones tuvieron una duración de ~1 s cada una, entre cada serie se dejaban 5 minutos de recuperación.

e. Equipo vibratorio

El estímulo vibratorio se aplicó mediante una plataforma comercial de WBV (Power Plate® Next Generation pro 5, Power Plate North America, Northbrook, IL, USA) que producía oscilaciones tri-planares sincrónicas (uniformes). El estímulo de WBV se aplicó a una frecuencia de 50 Hz con una amplitud alta de 2.2 mm_{p-p} (high). La aceleración que producía el estímulo de WBV fue de 99.71 m·s-2 medido mediante la suma de los vectores de las aceleraciones que registró un acelerómetro de tres ejes (Vibration Datalogger DT-178A, Ruby Electronics, Saratoga, USA). Para todas las condiciones, los sujetos calzaron el mismo calzado deportivo con el objetivo de estandarizar la absorción de vibraciones por el calzado (32).

f. Parámetros cinemáticos

Se monitorizaron las repeticiones mediante un encoder rotacional (Real Speed, Winlaborat V4.20, Buenos Aires, Argentina) unido a la barra (Figura 18). El encoder rotacional registró la posición de la carga con una precisión de 0.1 mm y el tiempo de las tareas con un 0.001 s de precisión. Se analizaron la potencia máxima y la aceleración máxima (fase concéntrica) de cada repetición.

g. Actividad electromiográfica superficial (EMG)

Se registró la actividad muscular mediante EMG del lado dominante para la escritura en el pectoral mayor (PM), cabeza larga del tríceps braquial (TB), bíceps braquial (BB), y bíceps femoral (BF). Se depiló y limpió el área con alcohol isopropílico antes de la colocación de los electrodos para reducir la impedancia de la piel. Los electrodos (separación de los inter-electrodos = 10 mm) se colocaron sobre la mitad del vientre muscular, de forma paralela a la dirección de las fibras de acuerdo con las recomendaciones del proyecto SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) (104).

Se utilizó la técnica del doble diferencias para detectar las señales mioeléctricas en crudo. Los electrodos superficiales estaban conectados a un convertidor de 16-bit AD (TrigoTMWireless System, Delsys Inc., Boston, MA, USA). Se pre-amplificaron las señales en crudo de EMG junto a los electrodos (ancho de banda de 20-450 Hz), amplificado a 4000 Hz, y almacenados en un ordenador. El análisis de datos de EMG se realizó utilizando un programa informático específico (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, Massachusetts, USA). Se obtuvo las medias de los datos de EMG mediante la raíz cuadrática media (rms) con el objetivo de obtener la amplitud media de la señal de EMG, y se seleccionó el valor máximo de cada repetición. Esta actividad muscular se normalizó en relación

con la señal de EMG obtenida durante la contracción voluntaria máxima (CMV).

h. Análisis estadístico

Los datos se analizaron utilizando PASW/SPSS Statistics 20 (SPSS Inc, Chicago, IL) y el nivel de significación se estableció en $p \leq 0.05$. Se comprobó la distribución normal de los datos mediante el test de Kolmogorov-Smirnov. Se utilizó el método de Greenhouse-Geisser para conocer la esfericidad. Se evaluaron mediante análisis de varianza para medidas repetidas en dos direcciones (ANOVA) de las variables dependientes (potencia máxima, aceleración máxima, EMGrms del TB, BB, PM y BF) para condición x carga. Donde se alcanzó el valor-F de significación, se realizó el procedimiento Bonferroni post hoc para la comparación por pares. Se analizó el tamaño del efecto estadístico, η^2, para determinar la magnitud del efecto independientemente del tamaño de la muestra. De las dos sesiones de familiarización, se calcularon los coeficientes de correlación intraclase para cada una de las variables dependientes para determinar la fiabilidad test-retest, obteniendo valores siempre mejores que 0.92 (ICC potencia máxima: 0.94, ICC aceleración máxima: 0.94, y ICC de EMGrms: 0.93). Los valores se presentaron con media ± DE.

VI. Resultados

a. Parámetros cinemáticos

Se observó un efecto en la interacción carga x condición (Figura 19) para la potencia máxima (PP) ($p=0.043$; $\eta^2=0.074$). Hubo un principal efecto carga indicando que se producían mayores PP durante cargas de 50% y 30% de 1RM comparado con 70% 1RM ($p<0.001$; $\eta^2=0.477$). Se encontró un efecto condición en PP ($p=0.043$; $\eta^2=0.074$).

No se encontró efecto de la interacción de carga x condición ($p=0.922$; $\eta^2=0.002$) para aceleración máxima (PA; Figura 19). Un efecto principal de condición indicó que PA durante WBV fue mayor que para la situación CTRL ($p=0.013$; $\eta^2=0.142$). También se encontró un efecto carga indicando que se obtenían menores PA durante las condiciones 50% y 70% 1RM que para la condición 30% 1RM ($p<0.001$; $\eta^2=0.903$).

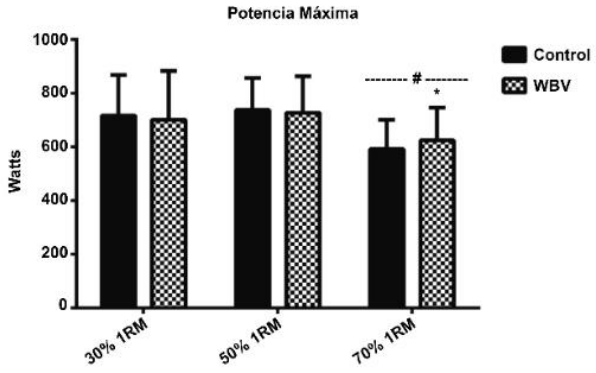


Figura 19. Potencia máxima durante las condiciones experimentales. # Diferencia significativa de las cargas 30% y 50 % 1RM ($p<0.05$). * Diferencia significativa de condición control para la misma carga ($p<0.05$).

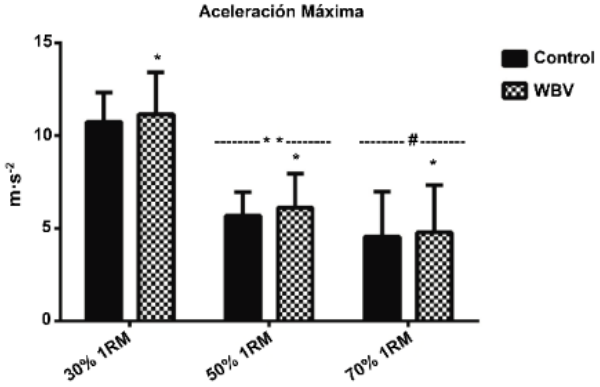


Figura 20. Aceleración máxima durante las condiciones experimentales. * Diferencia significativa de la condición control ($p<0.05$). ** Diferencia significativa de las cargas 30% y 50 % 1RM ($p<0.05$). # Diferencia significativa de la carga 30% 1RM ($p<0.05$).

b. Actividad electromiográfica (EMG) de superficie

Para la EMGrms de TB (Figura 21), no se encontró efecto para la interacción de condición x carga ($p=0.904$; $\eta^2=0.003$), a pesar de que se observó un principal efecto condición ($p=0.038$; $\eta^2=0.136$) y carga ($p=0.030$; $\eta^2=0.174$). Para condición, EMGrms fue mayor durante WBV que durante CTRL, y para carga de EMGrms fue mayor para 70% 1RM que para 30%y 50% de 1RM ($p=0.006$). Para BB EMGrms, no hubo efecto en la interacción de condición x carga ($p=0.091$; $\eta^2=0.075$), al igual que tampoco hubo efectos para condición ($p=0.934$; $\eta^2<0.001$) ni carga ($p=0.399$; $\eta^2<0.001$).

Para PM EMGrms (Figura 22), no hubo efectos para la interacción de condición x carga ($p=0.121$; $\eta^2=0.059$) y tampoco efecto para condición ($p=0.114$; $\eta^2=0.070$). Se encontró un efecto principal para carga, donde EMGrms fue mayor durante la condición 70% 1RM en comparación con 50% y 30% 1RM ($p<0.001$; $\eta^2=0.199$). Para BF EMGrms (Figura 22), no se observó efecto en la interacción de condición x carga ($p=0.761$; $\eta^2=0.008$), pero sí se encontró un principal efecto para condición ($p<0.001$; $\eta^2=0.363$) y carga ($p=0.010$; $\eta^2=0.122$). En el caso condición, BF RMG fue mayor para la condición WBV que para la condición CTRL. Para la carga, la condición 30% 1RM fue menos que para las condiciones 50% 1RM ($p=0.046$) y para 70% 1RM ($p=0.051$).

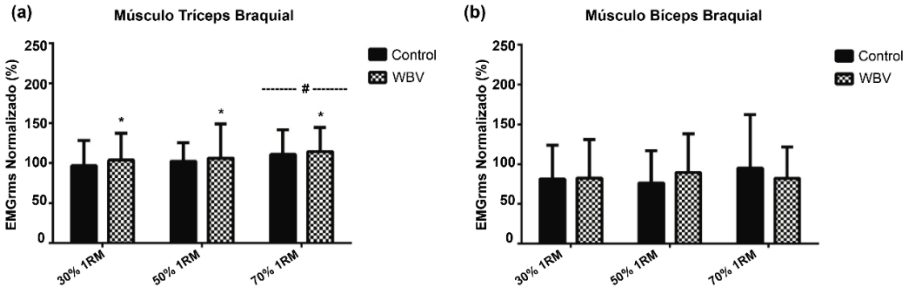


Figura 21. Datos de EMGrms normalizados para el músculo bíceps braquial (a) y músculo bíceps braquial (b). * Diferencia significativa de la condición control ($p<0.05$). # Diferencia significativa de las cargas 30% y 50% 1RM ($p<0.01$).

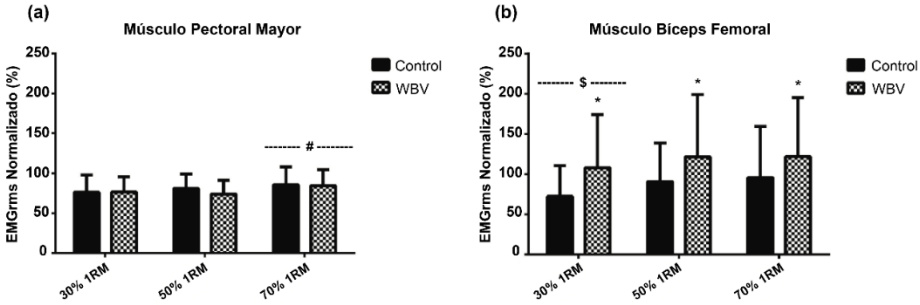


Figura 22. Datos de EMGrms normalizados para el músculo pectoral mayor (a) y músculo femoral (b). # Diferencia significativa de la condición control ($p<0.001$). $ Diferencia significativa de las cargas 50% y 70% 1RM ($p<0.01$).

V

10. Artículo V

I. Título

Efectos cruzados del *foam rolling* con vibración sobre la movilidad dorsal de tobillo.

II. Title

Cross transfer acute effects of foam rolling with vibration on ankle dorsiflexion range of motion.

III. Resumen

Foam roller es un instrumento utilizado como masaje para la rehabilitación y el rendimiento deportivo. Objetivo: Examinar los efectos del *foam roller* así como la combinación de *foam roller* con vibración aplicado en la musculatura de los flexores plantares de tobillo sobre la movilidad dorsal de tobillo, y observar el posible efecto cruzado. Metodología: Treinta y ocho alumnos participaron en este estudio (19 hombres y 19 mujeres). Este estudio investigó 3 condiciones (3 series de 20 s) en orden aleatorio (variables independientes): 1) *foam roller* (Roller), *2*) *foam roller* y vibración (Roller+VIB), y 3) sin *foam roller* ni vibración (Control) para determinar si *foam roller* con o sin vibración beneficiarán la movilidad dorsal de tobillo. Se midió el ROM y la fuerza de flexión dorsal y plantar de tobillo en ambas piernas antes e inmediatamente después del tratamiento. Resultados: Se encontró un efecto cruzado en la pierna no estimulada. Hubo un efecto

significativo en la movilidad dorsal de tobillo para las condiciones de Roller y Roller+VIB (6% y 7%, p<0.001). Conclusión: El masaje con *foam roller* y el estímulo vibratorio + masaje con *foam roller* aumenta la movilidad de tobillo produciendo un efecto cruzado.

IV. Abstract

Foam roller is a device used as a massage intervention for rehabilitation and fitness performance. Objective: To examine the effects on the ankle dorsiflexion mobility of the foam roller as well as the combination of foam roller and vibration applied to the ankle plantarflexors muscles, and to observe the possible cross-effect. Methods: Thirty-eight undergraduate students participated in the study (19 males and 19 females). This study investigated three conditions (3 sets of 20 s) were performed in a randomized order (independent variables): 1) foam roller (Roller), 2) foam roller and vibration (Roller+VIB), and 3) no foam roller or vibration (Control) to determine whether of foam roller with or without vibration would benefit ankle dorsiflexion mobility. Ankle dorsiflexion ROM and plantar flexor were measured in both legs before and immediately after the treatment. Results: A cross-effect was found in the non-stimulated leg. There was a significant effect on ankle mobility of Roller and Roller+VIB conditions (6% and 7%, p<0.001). Conclusion: Foam roller massage and vibration stimulus + foam roller massage increase ankle mobility producing a cross-effect.

V. Metodología

a. Diseño experimental

Este estudio investigó si 3 series de 20 s de *foam roller* con y sin vibración beneficiarían la movilidad dorsal de tobillo. Se midió el rango de movimiento (ROM) de dorsiflexión de tobillo y de flexión plantar en ambas piernas antes e inmediatamente después del tratamiento. Se realizaron de forma aleatoria tres condiciones diferentes (variables independientes): 1) *foam roller* (Roller), 2) *foam roller* y vibración (Roller + WBV), y 3) no *foam roller* ni vibración (Control). Todos los tratamientos se aplicaron sobre la pierna dominante y estuvieron separadas entre ellas con al menos 48 horas y se realizaron a la misma hora del día para tener en cuenta los biorritmos diarios. Para determinar la pierna dominante de los participantes se eligió la preferente a la hora de golpear un balón.

b. Participantes

Treinta y ocho estudiantes participaron en el estudio, 19 mujeres (19.5 ± 7.2 años de edad, 167.8 ± 0.1 cm, 59.2 ± 2.2 kg) y 19 hombres (21.8 ± 2.7 años, 178.9 ± 0.1 cm, 73.7 ± 9.1 kg). Una mujer y cinco hombres señalaron la pierna izquierda como dominante. Todos los participantes realizaron las 3 condiciones para minimizar la variación inter-individuos en la respuesta muscular. Los participantes eran físicamente activos, ninguno

comenzó un programa sistemático de entrenamiento físico durante la recolección de datos o al menos dos meses antes al comienzo del estudio. Antes de la recolección de datos, los participantes fueron informados de los requerimientos asociados con la participación en el estudio y se les suministró un consentimiento informado. Los criterios de exclusión fueron diabetes, epilepsia, piedras en la vesícula, piedras en el riñón, enfermedades cardiovasculares, prótesis articulares, trombosis reciente, al igual que problemas musculoesqueléticos. Se solicitó a los participantes mantener los hábitos alimentarios, de sueño y de bebida durante el estudio. Entre dos y tres días antes de las sesiones de registro, los participantes asistieron a una sesión de familiarización. El estudio se llevó a cabo de acuerdo con la declaración de Helsinki.

c. Foam Rolling y Vibración

En el presente estudio se utilizó un *foam roller* comercial (Vyper®, Hyperice, Irvine, USA) con 3 frecuencias de vibración diferentes que producía oscilaciones uniformes. La frecuencia a las que se realizó el tratamiento fue 49 Hz (vibración media). Durante todas las condiciones, los participantes no llevaban ningún tipo de prenda sobre las piernas o calcetines.

d. Medición del ROM de tobillo

El ROM de dosrsiflexión de tobillo se midió utilizando el sistema de Leg Motion® (Check your MOtion®, Albacete, Spain), que es una herramienta portátil utilizada en la medición de la dorsiflexión de tobillo durante la zancada en bipedestación (109). Se midió este test antes (Pre) y después (Post) de cada condición. Todos los registros fueron realizados por el mismo investigador de acuerdo con el protocolo de fiabilidad establecido por Ortega et al. (110). Antes de realizar el test de movilidad dorsal de tobillo, se llevaron a cabo dos intentos de calentamiento y el tercer intento fue el registrado. Los participantes se colocaban con las manos en las caderas, y situaban el pie del tobillo a registrar en la mitad de la línea longitudinal justo detrás de la línea transversal de la plataforma. El pie contralateral se colocó en el lateral de la plataforma. Manteniendo esta posición, los participantes realizaban una zancada en la que la rodilla se flexiona con el objetivo de contactar la parte anterior de la rodilla con la varilla metálica. La varilla de metal avanzaba separándose de la rodilla cuando los participantes eran capaces de mantener el talón y rodilla en contacto. La distancia alcanzada se midió en centímetros. Se realizaron tres intentos con cada tobillo (dominante y no-dominante) con 10 s de recuperación pasiva entre repeticiones. Se seleccionó el valor obtenido en la tercera repetición de cada tobillo para el análisis del ROM de dorsiflexión en carga (DF ROM) (111).

e. Contracción Isométrica Voluntaria Máxima

Se utilizó un aparato de medición de la fuerza de tobillo diseñado específicamente para medir el momento de fuerza isométrico de flexión plantar (PF) y dorsiflexión (DF). Los participantes se sentaban en una silla, con el tronco, muslo, pierna y pie fijados a la silla y al sistema de medición del momento de fuerza. Se calculó la DF y PF como la fuerza de tensión y compresión de la célula de carga (Winlaborat V4.20, Buenos Aires, Argentina).

Los participantes realizaban tres repeticiones de máximo esfuerzo con 1 min de descanso entre repeticiones para minimizar la fatiga muscular. Se calculó la media de las tres medidas. Se midió en un día diferente DF ROM, PF y DF, para determinar la fiabilidad test-retes de cada medición, calculando los coeficientes de correlación intraclase (ICC).

f. Protocolo

Todas las sesiones experimentales comenzaban con un calentamiento que consistía en 10 elevaciones de talones, con una duración de un segundo de subida y un segundo de descenso, hasta el contacto de los talones con el suelo. Cada participante realizó tres condiciones separadas en orden aleatorio, encontrándose descalzos; las condiciones fueron: 1) Roller (únicamente masaje con *foam roller*), 2) Roller + VIB (masaje con *foam roller* y vibración a 49 Hz), 3) Control (sentado en una silla).

El masaje con *foam roller* consistió en 3 series de 20 s de duración con un descanso de 10 s entre series. Para la condición de Control los participantes estuvieron sentados la misma duración que las condiciones experimentales. El *foam rolling* se realizó en sedestación con las piernas en extensión y los pies relajados como se muestra en la figura 23. Se solicitó a los pacientes la utilización de los brazos para desplazar su cuerpo adelante y atrás, el masaje abarcó desde la fosa poplítea hasta el tendón de Aquiles, con un movimiento continuo y suave en sentido longitudinal, de 3 s avance y 1 s retroceso, y después de forma viceversa desde el tendón de Aquiles hacia la fosa poplítea. Se enseñó a los participantes a desplazar toda la presión a la pierna dominante, dándoles *feedback* con una báscula en la que apoyaban su pierna contralateral, de esta forma se evitaba el exceso de presión en la pierna contralateral. Las medidas de DF ROM, PF, y DF se realizaron antes e inmediatamente después del tratamiento, en ambas piernas de forma aleatoria.

Figura 23. Técnica de *foam rolling*. De izquierda a derecha; aplicación en zona media, zona lateral y zona medial.

g. Análisis estadístico

Los datos se analizaron utilizando el programa PASW/SPSS Stadistics 20 (SPSS Inc, Chicago, IL) y el nivel de significación se estableció en $p \leq 0.05$. Se comprobó la distribución normal de todas las mediciones mediante el test Kolmogorov-Smirnov. Se comprobó la esfericidad mediante el método Greenhouse-Geisser.

Las variables dependientes (DF ROM, PF y DF) se analizaron con el análisis de varianza de medidas repetidas (ANOVA) para condición x tiempo. En los casos en los que se alcanzaba el valor F de significación, se realizó una comparación por pares mediante el procedimiento Bonferroni post hoc. El tamaño del efecto estadístico, η^2, fue analizado para determinar la magnitud del efecto de forma independiente al tamaño de la muestra. Los valores se presentaron mediante la media ± desviación estándar (DE).

VI. Resultados

Los ICC de DF ROM, PF y DF fueron 0.98, 0.87 y 0.89, respectivamente.

a. ROM de tobillo

El ROM de dorsiflexión de tobillo fue mayor en Roller y Roller+VIB en comparación con Control para ambas piernas ($p>0.001$; $\eta^2=0.394$). Tras la condición Roller, las piernas

dominante y no-dominante mostraron una mejora de un 6% del ROM de dorsiflexión de tobillo, mientras que para la condición de Roller+VIB la pierna dominante aumentó un 7% y la pierna no-dominante un 5% (Figura 24a y 24b). Se observó un efecto tiempo significativo ($p>0.001$; $\eta^2=0.762$), para todas las condiciones, al igual que un efecto pierna ($p>0.05$; $\eta^2=0.099$) (Figura 24a y 24b).

b. Contracción Voluntaria Máxima

No hubo diferencias significativas en el PF (Figura 24c and 24d) ni en DF (Figura 24e y 24f) al igual que entre condiciones ($p>0.05$).

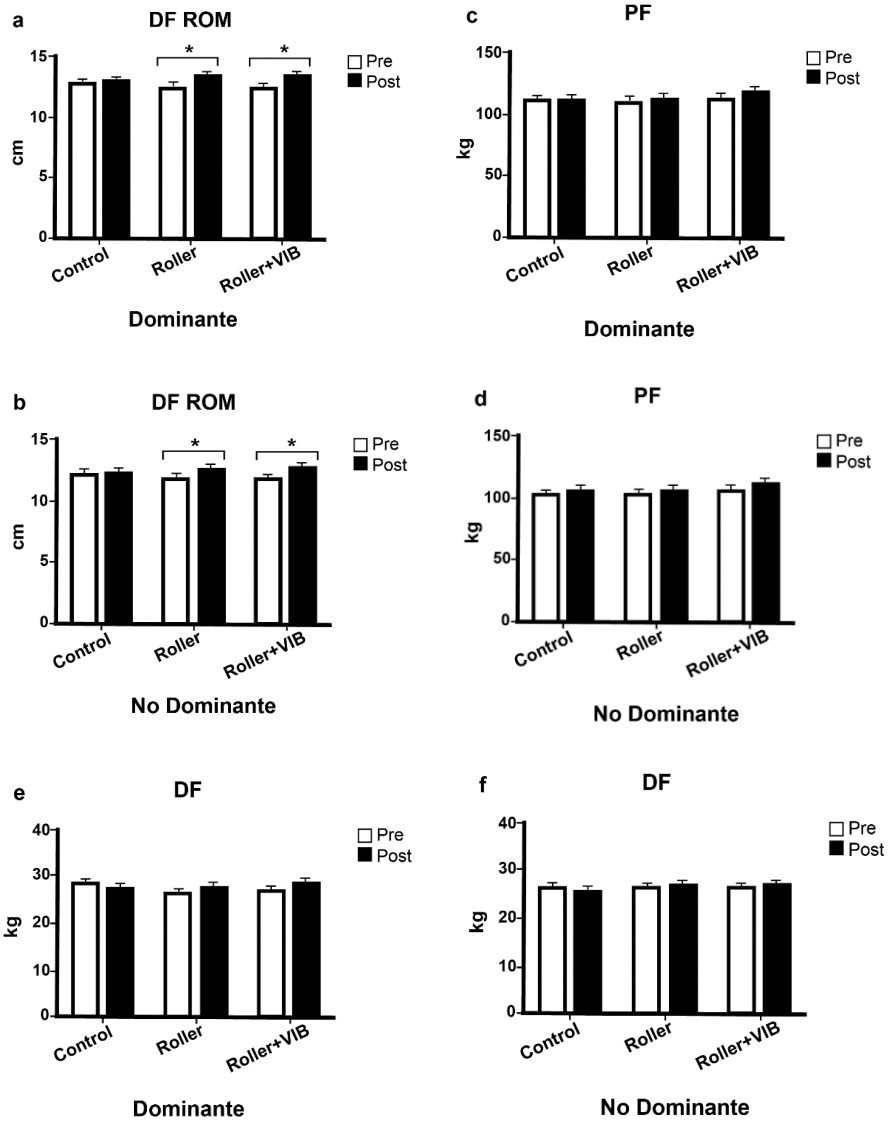


Figura 24. a & b rango articular de movimiento de dorsiflexión de tobillo (DF ROM) de la pierna dominante y no dominante; c & d fuerza de flexión plantar de tobillo (PF) de la pierna dominante y no dominante; e & f fuerza de flexión dorsal de tobillo (DF) de la pierna dominante y no dominante.

11. Discusión

El principal hallazgo de este proyecto de tesis ha sido que el estímulo vibratorio produce aumentos en la actividad neuromuscular en la musculatura alejada del foco vibratorio, además de en la musculatura estimulada.

Para optimizar la potencia muscular mediante plataformas de vibración sincrónica, se ha demostrado que frecuencias altas de WBV 45-50 Hz a un amplitud fija puede aumentar significativamente la EMG durante la exposición, y tras la exposición en comparación con frecuencias de 20-35 Hz (6, 14, 112). De acuerdo con Ronnestad (112), la frecuencia de vibración de 50 Hz puede producir mayor excitabilidad en el área motora que una frecuencia de WBV inferior, debido a que, la activación óptima de la unidad motora del cuádriceps se encuentra en un rango de 50-60 impulsos por segundo para alcanzar la máxima fuerza (113); este hecho justifica que en el **estudio I,** el estímulo de mayor frecuencia fue el que produjo mayor activación en la musculatura de VL y GM. Por otra parte, de acuerdo con los resultados obtenidos en el estudio I los cuales muestran un aumento significativo (5-7%) en la velocidad de ejecución de prensa de pierna unilateral para ambas piernas (estimulada y no estimulada), encontramos artículos previos que demostraron un aumento en la potencia bilateral en sentadilla (68), momento de fuerza isocinético de rodilla de carácter unilateral (114, 115) y fuerza isométrica de extensión de rodilla unilateral (67).

Actualmente, el efecto *cross education* es evidente, se han mostrado aumentos de fuerza en el miembro no entrenado, tras entrenamiento de fuerza unilateral (116, 117), lo cual se atribuye a adaptaciones neurales (117). El *cross education* se produce en ausencia de actividad muscular, crecimiento del área de sección transversal y de actividad muscular enzimática (117, 118). En el estudio I se encontraron aumentos en la velocidad (4-5%) tras la aplicación del estímulo vibratorio, ya que WBV produce efectos neurales de potenciación similares que el entrenamiento de fuerza (22). Se registraron aumentos de EMG en la pierna no entrenada tras la aplicación del estímulo, lo cual sugiere modificaciones en el control neural. Actualmente, no existe un consenso respecto a los mecanismos que producen *cross education*, pero se cree que estas modificaciones neurales se deben a las áreas corticales y espinales (117, 119) que son responsables de la respuesta excitatoria del área apropiada de la corteza durante contracciones voluntarias (80).

En el **estudio II** se ha encontrado que la plataforma de vibraciones produjo una disminución en la coactivación de los extensores, manteniendo la contracción máxima voluntaria durante una serie de repeticiones de presión manual. Este hallazgo demuestra que WBV mejora la coordinación muscular, como demostraron estudios previos en ejercicios dinámicos (18, 120) como flexión de codo (120) y extensión de codo (120); sin embargo, el estudio de Mischi y Cardinale (121) demostró un incremento en la coactivación de los flexores de codo durante un

ejercicio de extensión de codo. Por otra parte, se han encontrado aumentos significativos en la actividad muscular del bíceps braquial y el gastrocnemio medial con el estímulo vibratorio, estos resultados se basan en un estudio realizado por Wirth et al. (122) en el cual se encontró un aumento de la activación muscular debido a WBV durante ejercicios estáticos de tronco; dependiendo de dos factores; distancia del músculo a la plataforma vibratoria y requerimiento de estabilidad del ejercicio que se esté realizando.

El principal resultado encontrado en el **estudio III** fue un aumento de la activación muscular de todos los músculos analizados con la combinación de WBV y el ejercicio de *battling rope.* Este incremento de la activación muscular debido a WBV se ha encontrado tanto en las extremidades superiores como en las extremidades inferiores en diferentes estudios previos (5, 6, 14, 31-35, 123, 124). Como en el estudio anterior, en este caso se encontró una disminución en la coactivación de EMG del tríceps braquial con aumento de la activación en el bíceps braquial durante las condiciones con estímulo WBV. El estímulo vibratorio aumentó la frecuencia de movimiento de los brazos durante el *battling rope*, esto puede ser debido a la mejora en la coactivación muscular inducida por WBV.

En el **estudio IV** se encontró que el estímulo vibratorio produjo un aumento en la potencia pico al realizar un ejercicio de press banca declinado con carga alta. También la aceleración pico se vio incrementada con el estímulo de WBV. Estos aumentos pueden deberse principalmente al aumento de la actividad muscular del

tríceps braquial. La mayoría de los estudios han utilizado la plataforma vibratoria para analizar los efectos en el miembro inferior (5, 14, 31, 32, 125); sin embargo, en este estudio, como en el anterior, también se han demostrado efectos en el miembro superior (101). El ejercicio con carga alta es el que experimentó mayores aumentos en la actividad muscular, debido a que induce un aumento en la sensibilidad de las aferencias de los husos musculares (126, 127). El tríceps braquial experimentó un aumento en su actividad durante el ejercicio de press banca declinado con carga elevada y vibración, lo que se relaciona con los aumentos en los parámetros cinemáticos (7, 34); por el contrario, el bíceps braquial no aumentó su actividad, lo que sugiere que no hubo un aumento en la co-inhibición del músculo antagonista, lo cual pudo aumentar también los valores mencionados. La posición adoptada en la plataforma de fuerza de un puente de isquiosurales ha permitido demostrar un aumento en la actividad del bíceps femoral, similar al que se puede encontrar en el cuádriceps en posición de sentadilla tanto para un ejercicio estático como dinámico (5, 14, 31, 32).

El principal hallazgo encontrado en el **estudio V** fue que, el masaje con *foam roller* o el tratamiento conjunto del masaje con *foam roller* y vibración sobre la musculatura del tríceps sural de la pierna dominante, aumenta la movilidad dorsal de tobillo en ambas piernas, tratada y contralateral no tratada. Sin embargo, no se encontraron efectos significativos en la contracción isométrica voluntaria máxima de flexión plantar y dorsal de tobillo. Un estudio

reciente (128) encontró que el *foam rolling* puede tener una influencia positiva en el ROM de dorsiflexión de tobillo siendo capaz de producir efectos cruzados en la pierna contralateral. Un estudio realizado por Pellegrini y col. (129), investigó los efectos agudos de WBV en la activación voluntaria de los flexores plantares en adultos sanos concluyendo que tras 5 series de 1 min de estiramiento de los flexores plantares con WBV, el momento de fuerza submáximo de los flexores plantares aumentó, estos resultados se contraponen a los encontrados en el estudio V. Estas conclusiones se justifican mediante los resultados hallados en el estudio II, donde mayores focos de estímulo vibratorio produjeron mayores aumentos de fuerza. Por otra parte el ejercicio analizado en el estudio de Pellegrini y col. (129) fue un ejercicio isocinético mientras que en el estudio V fue un ejercicio isométrico. De acuerdo con Harwood y cols. (130), la fuerza isométrica de los flexores plantares disminuye tras 5 series de 60 s de WBV, pudiendo ser provocado por el compromiso de la vía I_a. Un artículo reciente ha analizado los efectos del *foam roller* en la recuperación muscular tras ejercicio que induce daño muscular, concluyendo que el *foam roller* no tiene efectos en el rendimiento, morfología y oxigenación de los flexores plantares, excepto una demostrada disminución del umbral de dolor (131).

Sin embargo, no se encontró que el ROM de flexión dorsal presente diferencias para los efectos obtenidos entre el tratamiento con *foam roller* únicamente o la aplicación simultánea con vibraciones.

Los efectos encontrados en la movilidad dorsal de tobillo, se explican mediante elementos viscoelásticos de la unidad miotendinosa (132, 133) y la tolerancia al estiramiento (134).

Los aumentos encontrados en la movilidad dorsal de tobillo de la pierna contralateral, se explican mediante la estimulación global de los mecanorreceptotes, lo cual coincide con la idea de efecto cruzado del miembro contralateral (128).

12. Conclusiones

La principal conclusión de este proyecto de tesis es que el estímulo vibratorio produce efectos neuromusculares agudos en zonas alejadas del foco vibratorio:

Las conclusiones específicas son las siguientes:

I. La aplicación del estímulo vibratorio produce un efecto neuromuscular cruzado en miembro inferior no estimulado en sujetos sanos.
II. Varios focos vibratorios producen mayores efectos neuromusculares que un único foco vibratorio.
III. La combinación de un ejercicio de los miembros superiores con la estimulación vibratoria de cuerpo completo incrementa los efectos neuromusculares agudos.
IV. La aplicación de un estímulo vibratorio en los miembros inferiores aumenta la potencia y actividad neuromuscular aguda durante un ejercicio de press banca con diferentes cargas.
V. El estímulo vibratorio sumado al masaje con foam roller genera similares cambios que la aplicación única del masaje con foam roller en la musculatura flexora dorsal, produce aumentos de la movilidad de dorsal de tobillo observándose fenómeno cruzado, sin generar cambios en la fuerza de flexo-extensión del tobillo.

13. Conclusions

The main conclusion of the present thesis is vibration stimulus evoked acute neuromuscular effects in muscles that are far from the vibration focus.

The specific conclusions are the following:

I. *The application of a vibration stimulus produce a cross-education effect in the non-stimulated leg in health subjects.*
II. *Several vibration focus produce greater neuromuscular effects than a unique vibration focus.*
III. *Am upper body exercise superimposed whole body vibration increase neuromuscular acute effects.*
IV. *The application of a vibration stimulus on lower body increase power and acute neuromuscular activity during a bench press exercise with different loads.*
V. *The vibration stimulus superimposed to the foam roller massage produce similar changes on ankle mobility than only applying foam roller massage on the ankle flexors muscles, finding a cross-education effect and no changes on the ankle flexo-extension strength.*

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15. Anexos

A continuación se exponen los artículos publicados sobre este proyecto de tesis:

- Artículo I
- Artículo II
- Artículo III
- Artículo IV
- Artículo V

Artículo I

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Original Article

Hylonome

Acute unilateral leg vibration exercise improves contralateral neuromuscular performance

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Abstract

Objectives: To examine the post-exercise cross-transfer effects of acute whole body vibration (WBV). **Methods:** Seventeen healthy male volunteers (20.8±1.2 y) performed three unilateral vibration conditions in a randomized order: 1) WBV-50 Hz [high amplitude]; 2) WBV-30 Hz [low amplitude]; and 3) a control no WBV condition (Sham) applied to the dominant leg. Each condition involved maximal voluntary isometric contractions (MVC) followed by three leg press explosive repetitions (40% MVC) with non-dominant and dominant legs; which were conducted prior to and post vibration (immediately; 2 min and 5 min). Surface electromygraphy (sEMG) of the vastus lateralis (VL) and medial gastrocnemius (MG) were measured throughout each condition. **Results:** A condition x leg x time interaction effect was detected (p=0.001) where 50 Hz-High in the stimulated leg enhanced mean velocity at post-2 min compared to 30 Hz-Low and Sham, remaining elevated at post-5 min. Similarly, 50 Hz-High in the non-stimulated leg increased mean velocity at post-immediately and post-2 min compared to 30 Hz-Low and Sham. There were no changes in sEMG of VL and GM in the stimulated and non-stimulated post-conditions. **Conclusion:** WBV (50 Hz) can augment cross-transfer in neuromuscular performance. WBV could provide an alternate method of unilateral training to promote cross education explosive strength.

Keywords: Sinusoidal Vibration, Electromyography, Power, Vibration Exercise, Cross-education

Introduction

Whole-body vibration (WBV) exercise has become a popular health and fitness tool over the past decade. Typically, WBV exercise involves intermittent exposures to a vibration stimulus while performing traditional body weight exercises such as squats or lunges on a ground-based platform. Several WBV studies have demonstrated that higher frequencies of vibration combined with higher amplitudes result in increased muscle activity[1-3], suggesting an increased stimulus. Because of the increasing popularity, much research has been performed to understand both if WBV exercise is beneficial for users and if so how WBV is resulting in these benefits.

An early suggestion was that WBV exercise improved neuromuscular function[4-7], though whether these include increases in muscle strength remains equivocal[5,8]. However, WBV exercise has demonstrated acute increases in strength following a WBV exposure suggesting a degree of neuromuscular potentiation[9-11]. Performing exercises on a synchronously (uniform vertical vibrations) oscillating platform induces short and rapid changes in muscle fibre length stimulating reflexive muscle contractions in a response akin to monosynaptic reflexes[12-14]. This response results in an increase in muscle activity[1,2,15,16], enhanced excitability of the cortical motor pathway, as well as modulation of intracortical circuits[17]. The mechanical vibration stimulus may also affect skin and joint receptors that provide sensory input to the gamma motor system increasing the sensitivity and responsiveness of the muscle spindle to further mechanical perturbations[18-20]. Though several studies have investigated the potential of WBV to improve subsequent performance[21-24], it is not well understood whether unilateral exposure to WBV will cause improvements in performance of the other leg.

Recently, it was demonstrated that 3 weeks of unilateral training (3 sessions per week) with the addition of WBV (35 Hz, 2.5 mm) did not further augment the cross-transfer of strength compared to the same training without WBV[25]. While

The authors have no conflict of interest.

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this suggests that 9 sessions over 3 weeks was not sufficient to induce an adaptation they only employed one vibration frequency over the 3 weeks and utilized large external loads that may have diminished the stimulus generated by the WBV platform. Therefore, before more training studies are performed, it seems practical to examine if there is an acute cross-transfer effect with WBV exposure. The practical importance of the effects of WBV on the cross-transfer of strength are also clinically important in rehabilitation settings for individuals with compromised capacity to use/train one limb due to injury or limb immobilization following surgery[25-27]. Thus, the aim of this study was to analyze the potential post-exercise cross-transfer effects of WBV by muscle activity and neuromuscular performance of explosive repetitions after WBV exposure (30 s duration) to determine if WBV exposure has a residual effect on contralateral leg. It was hypothesized that WBV would potentiate the neuromuscular system by improving neuromuscular performance of explosive movements.

Materials and methods

Experimental design

This study investigated whether 30 s of WBV exposure during a one-legged static semi-squat would benefit muscle performance in the non-exposed contralateral leg. Muscle activity and neuromuscular performance of leg press explosive repetitions at 40% MVC were measured before, immediately (within 30 s), 2, and 5 min post-WBV exposure. Three different exercise conditions were performed in a randomized order (independent variables): 1) 50 Hz with high amplitude (50 Hz-High), 2) 30 Hz with low amplitude (30 Hz-Low), and 3) no WBV (Sham). All exercise conditions were separated by at least 2 days and were conducted at the same time of day to account for daily biorhythms. Thus, at the end of the experimental phase, all the participants had been tested for the three conditions. The participant's dominant leg was defined by their preference for kicking.

Participants

Seventeen undergraduate male students participated in the study (20.8±1.2 y, 179.7±0.2 cm, 76.0±8.5 kg, mean±SD). Each participant performed all 3 conditions to minimize inter-individual variance in neuromuscular response and 15 of the 17 participants indicated right leg dominance. All participants were recreationally active (physically active) but none were involved in a systematic exercise-training program at the time of data collection or for at least 2 months prior to the study. All participants were experienced with free-weight resistance exercises and training leading to failure. Prior to data collection participants were informed of the requirements associated with participation and provided written informed consent. Exclusion criteria were diabetes, epilepsy, gallstones, kidney stones, cardiovascular diseases, joint implants, recent thrombosis, as well as musculoskeletal problems. Participants were encouraged to maintain their dietary, sleeping, and drinking habits during participation in the study. One week before the testing sessions, subjects attended two familiarization sessions. The research project was conducted according to the Declaration of Helsinki and was approved by the University Review Board for use of Human Subjects.

Vibration equipment

The vibration stimulus consisted of commercial platform (Power Plate® Next Generation pro 5, Power Plate North America, Northbrook, Illinois, USA) that produced synchronous (uniform) tri-planar oscillations[28]. The acceleration of the vertical sinusoidal oscillations (z-axis) was measured using a uni-axial accelerometer in accordance with ISO2954 (Vibration meter VT-6360, Hong Kong, China). Vibration platform settings included a frequency of 50 Hz with the peak-to-peak displacement of 2.51 mm (High) or a frequency of 30 Hz with peak-to-peak displacement of 1.15 mm (Low). Measured accelerations were 100.6±0.24 $m \cdot s^{-2}$ (at 50 Hz) and 20.44±0.34 $m \cdot s^{-2}$ (at 30 Hz). During all conditions, subjects wore the same athletic shoes to standardize the damping of the vibration because of the footwear[16].

Neuromuscular performance measurement

During all experimental sessions, participants performed isometric MVC trials at 60°-knee flexion followed by dynamic explosive contraction at 40% MVC on an adapted horizontal leg press machine (Nautilus Strength System S912, Vancouver, Canada) unilaterally on non-dominant and dominant legs. For the isometric MVC trials, participants were instructed to contract as 'hard' and 'fast' as possible for ~3 s. They repeated this 3 times for each leg separated by 20 s followed by the other leg. A digital load cell (HCB200K100, Kern & Sohn GmbH, Balingen, Germany) attached to the Nautilus equipment cable was used to measure the parameters of each MVC repetition. Participants then rested for 5 min before performing 3 dynamic explosive contractions at 40% of their MVC for each leg separated by 20 s of rest where participants were again instructed to extend their knee(s) as 'fast' and hard as possible for 3 s. The main investigator provided verbal cues to ensure correct execution was maintained through all testing. The neuromuscular performance of each explosive repetition were monitored by a rotary encoder (Globus Real Power, Globus, Codogne, Italy) linked to the highest load plate on the machine. The rotary encoder recorded the position of the load plate within an accuracy of 0.1 mm and time events with an accuracy of 0.001 s. Mean velocity for each repetition was analysed. Velocity was determined using software provided by the rotary encoder as described previously[29,30].

Surface electromyographic activity (sEMG)

Muscle activity of the vastus lateralis (VL) and medial gastrocnemius (MG) muscles were measured using sEMG[2,15,16,31,32]. Prior to electrode placement, the area was shaved and cleaned with isopropyl alcohol to reduce skin impedance. The electrodes were placed over the midbelly of the muscle parallel to the direction of the fibres according to recommendations by the SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles)[33].

The double differential technique was used to detect myo-

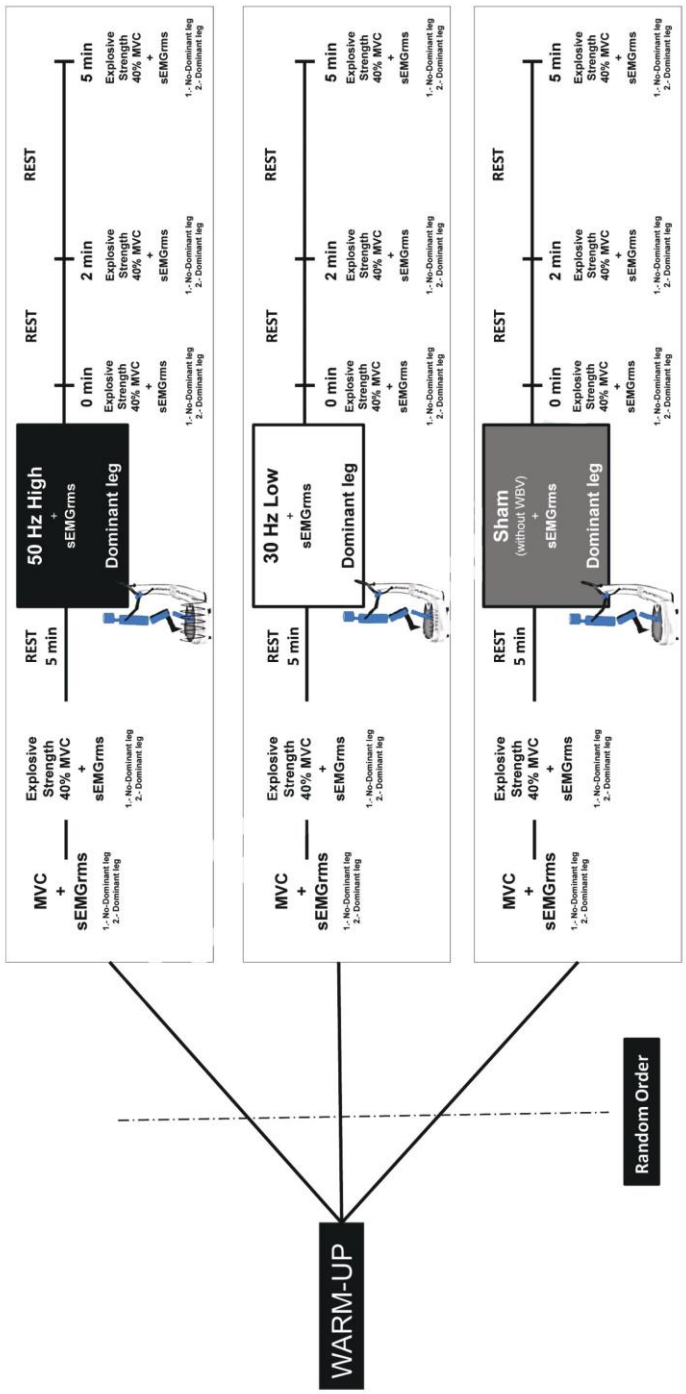
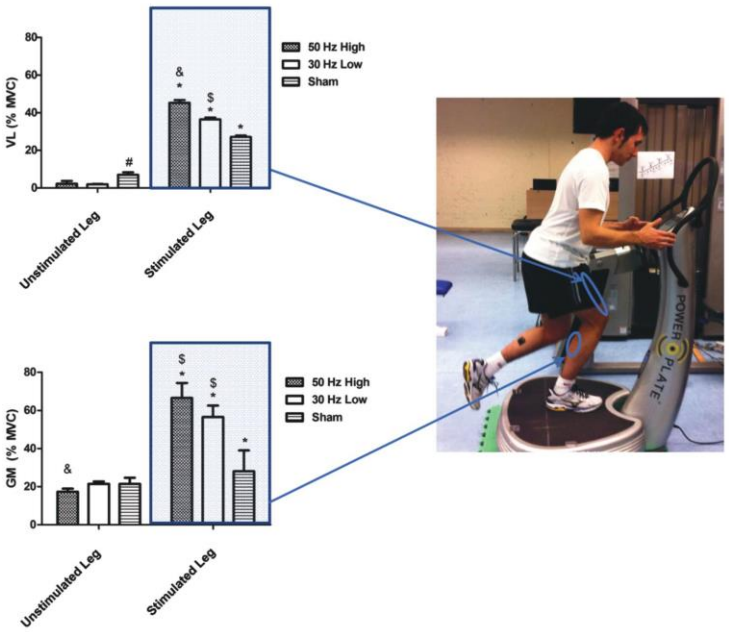


Figure 1. Experimental design.



* Statistically significant between legs ($p<0.001$)
# Statistically significant from 50 Hz High and 30 Hz Low ($p<0.001$).
& Statistically significant from Sham and 30 Hz Low ($p<0.001$).
$ Statistically significant from Sham ($p<0.001$).

Figure 2. sEMGrms of vastus lateralis (VL) and gastrocnemius medialis (GM) during unilateral WBV stimulation.

electric raw signals. The surface electrodes were connected to a 16-bit AD converter (Trigo™ Wireless System, Delsys Inc., Boston, MA, USA). Raw EMG signals were pre-amplified close to the electrodes (signal bandwidth of 20-450 Hz) and sampled at 4000 Hz and stored on a laptop. sEMG data analysis was performed using specific software (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, Massachusetts, USA). sEMG data was averaged by root mean square (rms) in order to obtain averaged amplitude of the sEMG signal. The sEMGrms values post-WBV of explosive 40% MVC test was normalized relative to maximum peak obtained in pre-WBV testing. For data analysis during WBV, only 20 s of the test condition were utilized (from 5 s to 25 s), which were normalized relative to MVC during the isometric test[1,2,15,16].

Protocol

In all experimental sessions, participants began with a warm-up consisting of 5 minutes of low-resistance (75 W) cycling on an ergometer. Each participant performed three separate conditions: 1) WBV-50 Hz [high amplitude]; 2) WBV-30 Hz [low amplitude]; and 3) a control no WBV condition (sham). Each session (Figure 1) was performed in random order beginning with the isometric MVC and dynamic explosive contractions at 40% MVC followed by 5 min rest. The experimental treatment then initiated with unilateral WBV stimulation on a vibration platform where participants were instructed to place their dominant foot in the middle of the platform and maintain a single-leg static squat at 60° knee flexion for 30 s, (knee fully extended=0°), which was measured by manual goniometer. The non-stimulated (non-dominant) leg remained off the platform behind the participant (Figure 2) and for balance the participants were allowed to touch the handrails. The time delay between exposure condition and post-testing was no longer than 5 seconds in duration.

Statistical analysis

The normality of the data was checked and subsequently confirmed with the Shapiro-Wilk test. Dependent variables were evaluated with a three-way repeated measures analysis of variance (ANOVA) on time x condition x leg. When a sig-

	Mean Velocity	VL $sEMG_{rms}$	GM $sEMG_{rms}$
Condition	p=0.091; n^2=0.139	**p=0.029; n^2=0.224**	p=0.717; n^2=0.030
Leg	**p=0.002; n^2=0.465**	p=0.121; n^2=0.163	p=0.298; n^2=0.098
Time	**p=0.002; n^2=0.264**	p=0.367; n^2=0.072	p=0.610; n^2=0.053
Condition*Leg	p=0.088; n^2=0.141	p=0.575; n^2=0.039	p=0.420; n^2=0.076
Condition*Time	**p<0.001; n^2=0.244**	p=0.139; n^2=0.107	p=0.255; n^2=0.108
Leg*Time	p=0.159; n^2=0.101	p=0.115; n^2=0.130	p=0.158; n^2=0.144
Condition*Leg*Time	**p=0.001; n^2=0.208**	p=0.850; n^2=0.031	**p=0.029; n^2=0.187**

Table 1. Summary of the main effects analyzed with the ANOVAs for the dependent variables.

	50Hz-High		30Hz-Low		Sham	
	Non-Stimulated	Stimulated	Non-Stimulated	Stimulated	Non-Stimulated	Stimulated
Pre	0.296±0.01	0.315±0.01	0.288±0.02	0.299$^{\$}$±0.01	0.285±0.02	0.302±0.01
Post-Immediately	0.312$^{*\#}$±0.01	0.325*±0.01	0.289±0.02	0.288$^{*\&}$±0.01	0.279±0.02	0.303±0.02
Post 2 min	0.309*±0.01	0.329*±0.01	0.289±0.02	0.306±0.01	0.288±0.02	0.309±0.02
Post 5 min	0.302±0.01	0.331*±0.01	0.282*±0.02	0.296$^{\&}$±0.01	0.288±0.02	0.285*±0.02

$^{\$}$ - Statistically significant between leg for experimental sessions (p<0.05).
* - Statistically significant from Pre at the same leg and experimental session (p<0.05).
$^{\&}$ - Statistically significant from Post 2 min at the same leg and experimental session (p<0.05).
$^{\#}$ - Statistically significant from Post 5 min at the same leg and experimental session (p<0.05).

Table 2. Pre and post times of mean velocity ($m \cdot s^{-1}$) for the three conditions.

nificant F-value was achieved, pairwise comparisons were performed using the Boferroni post hoc procedure. The level of significance was fixed at p≤0.05. The intraclass correlation coefficients (ICC's) were calculated for both the peak and mean velocity of the three explosive dynamic contractions at 40% MVC for each leg to determine test-retest reliability. The ICC's were greater than 0.92 indicating a high level of reproducibility in assessing the dependent variables was achieved. Values are expressed as mean±SEM and effects sizes were measured by partial Eta square (η^2).

Results

The summary of the 2-way and 3-way interactions as well as the main effects analyzed with the ANOVAs for the dependent variables are given in Table 1.

Neuromuscular performance

A main effect of the leg was observed indicating that the stimulated leg produced a faster mean velocity than the non-stimulated leg (p=0.002). Likewise, a time effect was significant where post-2 min produced the greatest change in mean velocity compared to other time points (pre, post-immediately and post-5 min, p=0.002). A significant interaction effect of condition and time (p<0.001) was observed indicating that 50Hz-High at post-2 min produced the greatest increase in mean velocity (Table 2). A condition x leg x time interaction effect was detected (p=0.001) where 50Hz-High of the stimulated leg enhanced mean velocity at post-2 min compared to 30Hz-Low and Sham and remained elevated at post-5 min. Likewise, 50Hz-High in the non-stimulated leg increased mean velocity at post-immediately and post-2 min compared to 30Hz-Low and Sham. The percentage of change for mean velocity is shown in Figure 3.

Muscle activity during unilateral WBV stimulation

WBV significantly increased sEMG VL and GM activity during exposure compared to Sham in the stimulated leg compared to the non-stimulated leg, where during 50Hz-High exposure significantly increased sEMG VL more than during 30Hz-Low exposure. There was no significant difference in the enhanced sEMG GM between the 50Hz-High and 30Hz-Low exposures (Figure 2).

Muscle activity post-WBV Exposure

There were no significant changes reported for sEMG of VL and GM post-WBV exposure indicating EMG was not enhanced sufficiently in either the stimulated and non-stimulated post-conditions (Figure 3). However, there was a significant condition effect for such that the Sham condition significantly increased (p<0.05) sEMG VL compared to 30 Hz (Table 3). A condition x leg x time interaction effect was noted where

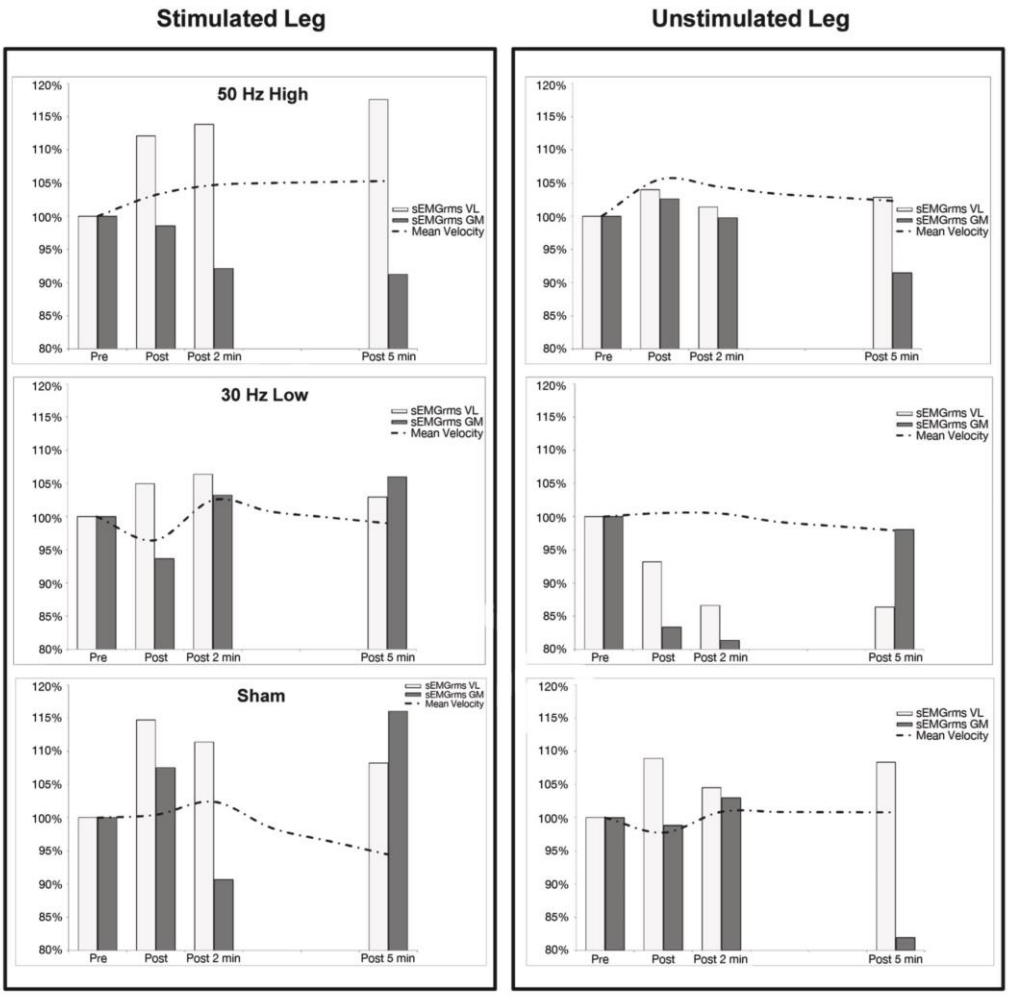


Figure 3. Percent of change for mean velocity and sEMG of vastus lateralis (VL) and gastrocnemius medialis (GM).

sEMG GM of the non-stimulated leg was significantly reduced ($p<0.05$) at post-5 min from 30Hz-Low compared to Sham (Table 4).

Discussion

The major finding of this study was that an acute WBV (50Hz) bout of 30 s augments cross-transfer in neuromuscular performance of explosive power parameters. To optimise muscle power from synchronous vibration platforms, such as the one used in this study, it has been advocated that higher WBV frequencies of 45-50 Hz at a fixed amplitude can significantly increase sEMG during exposure and acute power characteristics post-exposure compared to lower WBV frequencies of 20-35 Hz[1-3]. Similarly, 50Hz-High used in this current study elicited a significantly higher level of sEMG activity during WBV exposure in the VL compared to 30Hz-Low and Sham and both 30Hz-Low and 50Hz-High increased sEMG during exposure in the GM compared to Sham. According to Ronnestad[3] 50 Hz vibration frequency may provide a greater excita-

	50Hz-High		30Hz-Low		Sham	
	Non-Stimulated	Stimulated	Non-Stimulated	Stimulated	Non-Stimulated	Stimulated
Pre	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0
Post Immediately	104.0±9.0	112.1±5.5	93.2±9.2	105.0±7.5	108.9±5.1	114.7±6.5
Post 2 min	101.4±9.0	113.8±7.0	86.6±7.0	106.4±10.3	104.5±5.4	111.4±5.2
Post 5 min	102.8±9.0	117.6±7.0	86.4±5.9	102.9±10.6	108.3±5.6	108.2±6.5

Table 3. Pre and post times of $sEMG_{rms}$ VL (%) for the three conditions.

	50Hz-High		30Hz-Low		Sham	
	Non-Stimulated	Stimulated	Non-Stimulated	Stimulated	Non-Stimulated	Stimulated
Pre	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0	100.0±0.0
Post Immediately	102.6±7.6	98.6±5.8	83.4±11.1	93.7±4.4	98.8±11.2	107.5±10.3
Post 2 min	99.8±8.0	92.1±9.1	81.4±6.8	103.2±4.7	103.0±10.4	90.7±4.4
Post 5 min	91.5±7.6	91.2±9.8	98.0±14.2	106.0±5.1	81.9±10.1	116.0±5.4

Table 4. Pre and post Times of $sEMG_{rms}$ GM (%) for the three conditions.

tory stimulus to the motoneuron pool than a lower WBV frequency due the quadriceps relying on optimising a motor unit discharge rate of 50-60 impulses per second to reach maximum force[34].

Previously, it has been reported that following acute WBV power and strength performance is enhanced in bilateral countermovement vertical jump[11,35,36], bilateral squat power performance[23], unilateral knee isokinetic torque[37,38] and unilateral isometric knee extension force[36]. Significant increases (5-7%) in velocity have also been observed during single-leg press loads (70-130 kg) after unilateral WBV exposure (10 x 60 s)[10]; which is consistent with our muscle velocity enhancement (3-5%) of the stimulated and non-stimulated leg following 50 Hz-High.

It has been well documented that 'cross education' or 'cross training effect' enhances strength in the untrained contralateral limb from unilateral resistance training that relies on training specificity of the homologous muscles[39,40]. Many cross education studies have used various unilateral resistance training methods and loading parameters to elicit changes in contralateral strength[41], which have been attributed to neural adaptations[40]. It has been suggested that WBV elicits a neural potentiation effect similar to that of resistance training[42] due to its ability to increase acute strength parameters[9-11]. During WBV, the loading parameter is altered by adjusting the acceleration (vibration frequency and amplitude), which differs from conventional strength training the weight lifted is altered to modify the neuromuscular effects. In the current study the stimulus of 50 Hz-High significantly enhanced velocity (4-5%) in the non-stimulated leg; indicating that WBV can effectively induce cross education in the contralateral limb. To our knowledge, no other studies have reported a cross-transfer effect following acute WBV. However, Goodwill and Kidgell[25] investigated the short-term effect of 9 training sessions (3 per week, for 3 weeks) on unilateral resistance training with WBV and without WBV. They reported a significant increase in 1RM squat strength of 52.4% and 35.4% in the untrained leg with WBV and without WBV respectively indicating that the addition of WBV did not significantly augment muscle strength more effectively than resistance training alone. The discrepancy between these results[25] and our current data may be explained by WBV stimulus employed. Our current results used a higher frequency WBV stimulus (50 Hz) compared to a lower frequency in previous work (35 Hz)[25]. Perhaps a higher frequency is necessary to augment the cross-transfer of strength. Moreover, we used a relatively light external resistance (40% MVC) compared to much heavier loads (>75% 1-RM)[25] which may have altered the WBV stimulus (diminished the acceleration generated). Further, we applied WBV during explosive movements compared to a much slower contraction (3 sec concentric and 4 sec eccentric phases) in the work by Goodwill and Kidgell[25] that may also help explain our conflicting results. Our work also demonstrates an acute positive effect which may not be present after repeated WBV exposures[25], thus future research is warranted to clarify if these methodological differences are responsible for the divergent results.

From a review of resistance training studies, the extent of cross education appears on average to increase contralateral strength by 7.6%[39]), which is comparable with the current findings of a velocity improvement (3-5%) in the stimulated leg following 50 Hz-High. Likewise, a similar magnitude gain of 4-5% in velocity was also observed in the non-stimulated leg (50 Hz-High), which is in agreement with previous literature that strength transfer to the untrained limb is proportional to the strength gain observed in the trained limb[39,41]. This aug-

mentation of cross-transfer effects on strength could be clinically important in rehabilitation settings for individuals with compromised capacity to use/train one limb due to injury or limb immobilization following surgery[25-27].

One purported characteristic of cross education in the untrained leg indicates that it is likely to occur in the absence of muscle activity, cross sectional area growth, and muscle enzyme activity[40,43]. In cross education studies, it has been observed that sEMG remains inactive in the untrained limb during resistance training of the contralateral limb[44,45]. This was also evident in the present study; following WBV-50 Hz quiescent sEMG activity accompanied a muscle velocity gain suggesting modifications in neural control. Currently, there is no consensus on the mechanisms of cross education, however the likely candidates to eliciting neural modifications could be the cortical and spinal areas[26,40] that are responsible for excitatory responses of the appropriate cortex area during voluntary contractions[46]. Evidence suggests that the cross-transfer of resistance training could be due to supraspinal rather than spinal mechanisms[47]. Moreover, strength gained in an untrained leg may coincide with enhanced agonist activation[48], reduced antagonist activation[49], or increased synergist activation[50]. However, the level of contribution from the central nervous system remains speculative and requires further investigation.

Although WBV mechanisms are still being debated, it is thought that WBV causes a rapid reflex and stretch-shortening[14] where a temporal association exists between EMG activity and muscle contractile displacement[51] that is likely to involve the tonic vibration reflex (TVR)[13,14], thereby activating the muscle spindles and enhancing the excitatory drive reflex of the alpha motor neurons[8]. Additionally, WBV may have a positive influence on motor cortex excitability and voluntary drive. Recently, it has been observed when acute WBV was applied to the lower-body during or between resistance training sets it significantly increased upper body performance[52,53]. Likewise, Mileva et al.[17], reported increased corticospinal excitability and alteration of intracortical processes during WBV. The aforementioned studies indicate that the WBV facilitatory effects may influence the excitatory state of the peripheral and central structures of the brain, which could facilitate subsequent voluntary contractions. Contrary, Goodwill and Kidgell[25] reported a decrease in intracortical inhibition following 3 weeks of combined leg squat resistance and WBV training and although corticomotor excitability increased with the WBV combined training it was not significant to that of conventional leg squat resistance training. The authors acknowledge that various physiological pathways may be responsible for mediating different effects during and post-WBV.

While the results from the current study are important in the area of WBV literature it is not without its limitations. We only used healthy young males so our extrapolation of the present data to different participant populations should be made with caution. We did not measure any synergistic or antagonistic muscles involved, nor did we measure muscle force production, which could have further clarified some of the results. Further, our current study only used 2 WBV stimuli (low frequency, low amplitude and high frequency, high amplitude) and only tested neuromuscular performance at 40% of MVC of explosive muscle contractions so further research is warranted on other WBV stimuli and other types of muscle contractions.

In conclusion, the present study documents for the first time a cross-education effect following acute WBV-50 Hz, as demonstrated by the enhancement in muscle velocity from explosive unilateral leg press. This increase in explosive power and neuromuscular performance combined with the quiescent sEMG activity during and following WBV suggests neural drive was responsible for such an effect. However, the likely candidate mechanism of corticospinal and intracortical processes to explaining cross education for explosive movements requires additional research. The implications of this research could be beneficial in the rehabilitation field; often an injury can lead to a period of immobilisation and compromises neural function. However, WBV could provide an alternate method of unilateral training to promote cross education strength in reducing the functional loss of the affected limb.

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Artículo II

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Original Article

Hylonome

A comparison of different vibration exercise techniques on neuromuscular performance

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Abstract

The first purpose of this study was to determine the effects of whole-body vibration (WBV) exercise during an isometric handgrip exercise. The second purpose was to evaluate whether more than one vibratory focus would evoke an increase in the effects evoked by only one vibratory focus. The present study investigated whether WBV exposure during 10 repetitions of a handgrip dynamometer while standing on a WBV platform. Twenty-eight recreationally active university students completed 3 different test conditions, in random order: 1) grip dynamometer exercise with superimposed WBV and contralateral arm vibration (WBV+AV); 2) superimposed arm vibration only (AV); 3) grip dynamometer exercise without vibration (Control). The hand grip strength was slightly higher in the WBV condition as compared to the Control and AV conditions (1.1% and 3.6%, $p>0.05$, respectively). A main effect of the EMGrms of extensor digitorum muscle (ED) was observed indicating that the WBV+AV condition produced a lower co-activation of ED during a flexor digital task than the Control and AV ($p<0.05$) conditions. The application of WBV+AV may acutely increase muscle coordination and decreases the coactivation of ED. Furthermore, the muscle EMGrms showed increases in activation near the vibratory focus in both upper- and lower-body.

Keywords: Electromyography, Power, WBV, Hand Grip

Introduction

Vibration training has been investigated throughout the last decade as an alternative or complement method to traditional resistance programs for fitness improvements. Vibratory stimuli can be applied directly to the muscle belly[1] or the tendon muscle[2,3]; indirectly applied by gripping a vibration system[4], dumbbell[5], bar[6] or pulley system[7], or whole body vibration (WBV), in which the stimuli enters via the feet while standing on a vibration platform[8]. WBV has been the most studied method of vibration training. The principle reason for using WBV in muscle training is the strength and power improvements that people can get in a short period of time[9,10]. Numerous investigators have studied the effects that the vibratory platform exposure produces on the lower body. It has been shown to result in improvements in jump height[11], sprint performance[12]; metabolic[13] and hormonal[14] changes, and neuromuscular performance, both acute[8] and chronic[15].

The observed strength improvements, in the first few weeks of a training program, have been attributed to neural performance aspects, because changes in the morphology, architecture, and size of muscle tissue occur at a later stage[16,17]. Electromyography (EMG) activity increases in parallel with the levels of force used for training and reaches maximum with loads near maximal voluntary contraction[16]. Vibration training increases EMG activity on lower body[18-20] as well as on upper body muscles[3,21].

Previous studies have been found significant effects of vibration exposure on upper body muscular activity. Bosco et al.[21] found a significant increase in average electromyography (EMG) activity during upper body vibration and a significant increase in mechanical power during dynamic elbow flexion. Mischi and Cardinale[22] concluded that isometric elbow flexion and extension with superimposed vibration stimulation increasing the activation and coactivation of the biceps and triceps. However, there exist a large number of published articles related to the use of WBV to increase power and strength on

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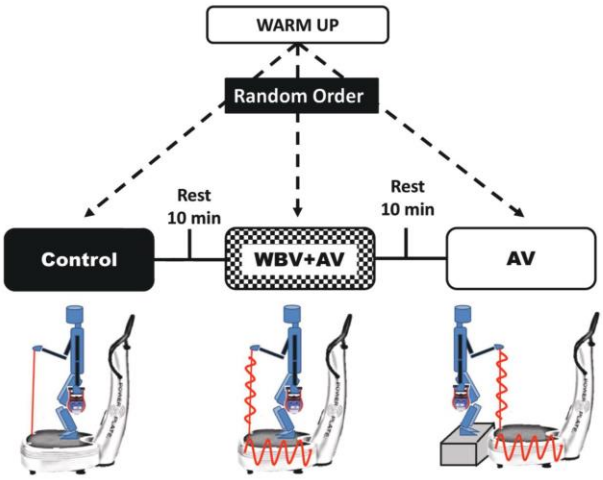

Figure 1. Experiment setup.

lower body muscular performance. Lamont et al.[10] found a significant augment to strength in an isometric squat test after resistance training was supplemented with WBV. Also, some studies have found significant effects on neuromuscular performance after a unilateral leg exposure to WBV on the contralateral leg not being stimulated[23]. This suggests definite central nervous system stimulation via WBV applications.

Only a few studies have investigated the effect of WBV on upper limbs, usually involving dynamic exercises[24]. A major reason for this lack of research is the attenuated vibration stimulus that reaches the upper limbs due to the distance between the vibration exposure (platform) and the upper body muscles. The soft tissue properties of the human body, combined with the muscular actions employed by the brain to control vibration exposure, results in less vibration stimulus reaching the upper body when standing on a vibration platform. Having said that, Marin et al.[25] found a significant increase in the number of maximal repetitions until exhaustion during a bicep curl set with WBV exposure. Another study found similar results during an elbow extension set with WBV until exhaustion[26]. To our knowledge, no previous studies have measured the effects of vibration stimuli via the feet on neuromuscular performance of upper limb muscles during an isometric exercise. Therefore, the current study sought to examine whether the use of WBV would improve performance on an isometric task in the upper body. Thus, the first purpose of this study was to determine the effects of WBV during an isometric hand-grip exercise. The second purpose was to evaluate whether more than one vibratory focus would evoke an increase in the effects evoked by only one vibratory focus. First, it was hypothesized that: i) vibration stimulus would provide an additional stimulus for neuromuscular system, increasing the isometric performance of the upper body, ii) more vibratory stimulus through both the arms and feet would evoke more effects than vibratory stimulus solely in the arms.

Methods

Experimental design

The present study investigated whether WBV exposure during 10 repetitions of a handgrip dynamometer while standing on a WBV platform under 3 different conditions, in random order, would benefit muscle performance (Figure 1). Three different conditions were performed: 1) grip dynamometer exercise with superimposed WBV and contralateral arm vibration (WBV+AV); 2) superimposed arm vibration only (AV); 3) grip dynamometer exercise without vibration (Control). Statistical analysis was conducted to evaluate for differences between the conditions.

Participants

Twenty-eight active male students participated in this study. The participants' mean (±*SD*) age, height and body mass were 22±1.6 years, 178.7±6.8 cm and 74.6±9 kg, respectively. The participants were physically active, but none were engaged in a systematic exercise program for at least 2 months before the data collection. All participants were experienced with isometric exercises and training to muscular failure. Exclusion criteria were diabetes, epilepsy, gallstones, kidney stones, cardiovascular diseases, joint implants, recent thrombosis, and musculoskeletal problems. For the purpose of testing, the participants' dominant arm was defined by their preference for writting. Participants were informed of the procedures and po-

tential risks associated with participation in the study, and they provided written informed consent. One week before the testing sessions, participants attended two familiarization sessions. The research project was conducted according to the Declaration of Helsinki and was approved by the University Review Board for use of Human Subjects.

Treatment protocol

Participants performed three sets on the vibration platform in random order, so that each subject was exposed to the three conditions (WBV+AV, AV, Control). The experimental protocol began with electrode placement, followed by a standardized warm-up consisting on 2 min slow jog, 5 dynamic warm-up exercises, 10 reps of each exercise, (pull-backs, butt kicks, knee to chest, squats, and lateral lunges), and 5 maximal hand-grip repetitions. Ten maximal hand-grip repetitions were performed using a hand-grip dynamometer (Grip Strength Dynamometer T.K.K.5401; Takei Scientific Instruments Co., Ltd, Niigata, Japan) in each set. Ten minutes rest was given between each set. Each repetition had an approximate duration of 2 seconds followed by 2 seconds of rest.

The isometric semi-squat exercise required participants to stand with feet shoulder-width apart, with 30° knee flexion (considering 0° as the anatomical position) on the vibration platform (Figure 1). Subject placement was measured by a goniometer. When the isometric bicep curl was added to isometric semi-squat participants held the Power Plate hand straps (used to transfer vibration to the upper body) with elbow flexion at 90°. Participants were asked to maximally contract their biceps using the hand straps at the same time as the hand-grip. Joint angles were carefully monitored during each repetition with verbal feedback provided by a trained researcher. During all conditions, participants wore the same athletic shoes to standardize the vibration stimulus across conditions.

Vibration equipment

The vibration stimulus was applied via a commercial platform (Pro5 Power plate, Power Plate International Ltd., London, UK). The acceleration of the vertical sinusoidal oscillations (z-axis) was measured using a uni-axial accelerometer in accordance with ISO2954 (Vibration meter VT-6360, Hong Kong, China). Vibration platform settings included a frequency of 50 Hz with the peak-to-peak displacement of 2.51 mm (High). Measured accelerations were 100.6±0.24 $m \cdot s^{-2}$ (at 50 Hz).

Surface electromyographic activity (EMG)

Muscle activity of long flexor radial digitorum (FR), extensor digitorum (ED), contralateral biceps brachii (BB) and gastrocnemius medialis (GM) was measured using EMG[21,27,28]. Prior to electrode placement, the area was shaved and cleaned with isopropyl alcohol to reduce skin impedance. The electrodes were placed over the midbelly of the muscle parallel to the direction of the fibres according to recommendations by the SENIAM project (Surface ElectroMyo-Graphy for the Non-Invasive Assessment of Muscles)[29]. The double differential technique was used to detect myoelectric raw signals. The surface electrodes were connected to a 16-bit AD converter (TrigoTMWireless System, Delsys Inc., Boston, MA, USA). Raw EMG signals were pre-amplified close to the electrodes (signal bandwidth of 20-450 Hz), sampled at 4000 Hz, and stored on a laptop. EMG data analysis was performed using computer software (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, Massachusetts, USA). The EMG data were averaged by root mean square (rms) in order to obtain averaged amplitude of the EMG signal, and the maximum value of each repetition was selected. Moreover, in order to obtain average frequency the signal was averaged by median frequency (MDF). EMG was registered during the 10 repetitions of each isometric set.

Statistical analysis

Data were analyzed using PASW/SPSS Statistics 20 (SPSS Inc, Chicago, IL) and significance level was set at $P \leq 0.05$. Values are presented as means ± standard error (SE). All the measures were normally distributed, as determined by the Kolmogorov-Smirnov test. Sphericity was tested by the Greenhouse-Geisser method. Dependent variables were evaluated with a 1-way repeated measures analysis of variance (ANOVA). Where significant F-values were achieved, pairwise comparisons were performed using the Boferroni post hoc procedure. Effect size statistic, η^2, was analyzed to determine the magnitude of the effect independent of sample size.

Results

Hand grip isometric force

Hand grip force was slightly higher in the WBV condition as compared to the Control and AV conditions (1.1% and 3.6%, respectively), however, no significant condition effect was observed ($p>0.05$; $\eta^2=0.048$) (Figure 2a). The maximal isometric force during the 10th repetition was significantly lower than the 6th repetition ($p<0.001$; $\eta^2=0.739$) in all three of the different conditions (Figure 2b). A significant interaction effect of condition and repetition ($p=0.047$; $\eta^2=0.057$) was observed on the 8th repetition between WBV+AV and AV, with the greatest values measured in the WBV+AV condition (Figure 2b).

Muscle activity Extensor and Flexor digitalis

A main effect of the ED EMGrms was observed indicating that the WBV+AV condition produced a lower co-activation of extensor digital during a flexor digital task than the Control and AV ($p<0.05$; $\eta^2=0.111$) conditions. There was no significant difference in the enhanced EMGrms ED between the Control and AV conditions (Figure 2c). Table 1 (ED) and Table 2 (FD) show the summary of the repetition effect as well as the main effects analyzed with the ANOVAs for the dependent variables in each of the 3 different conditions.

Muscle activity Biceps brachii and Gastrocnemius medialis

The EMGrms measured in the biceps brachii muscle during the WBV and AV conditions were significantly higher ($p<0.05$; $\eta^2=0.078$) than the Control (Figure 3a). A similar effect was

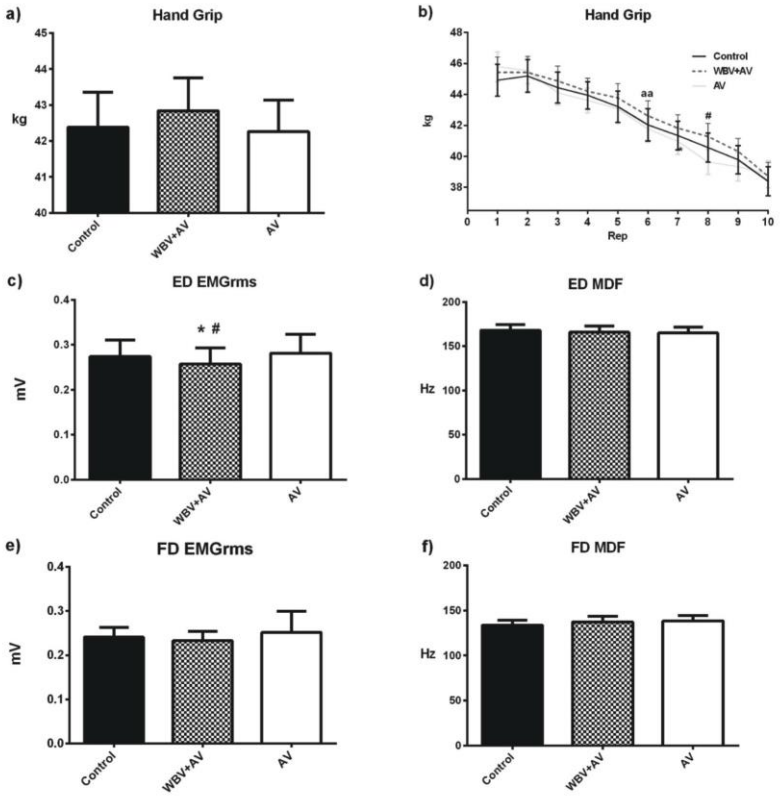

Figure 2. Hand grip strength and EMG results. WBV+AV, Whole body vibration and arm vibration; AV, arm vibration; ED, extensor digitalis; FD, flexor digitalis; EMGrms root mean square MDF, median frequency. [aa]Significant drop from 6 repeat in the three conditions ($p<0.001$). *Difference from Control condition ($p<0.05$). #Difference from AV condition ($p<0.05$).

	Extensor Digitorum Muscle					
	EMGrms (mV)			MDF (Hz)		
	Control	**WBV+AV**	**AV**	**Control**	**WBV+AV**	**AV**
Rep 1**	0.278±0.179	0.271±0.192	0.298±0.217	181.1±7.4	182.8±7.5	179.9±5.7
Rep 2##	0.273±0.195	0.264±0.209	0.287±0.233	175.2±6.9	172.1±7.1	168.6±6.3
Rep 3	0.283±0.200	0.265±0.201	0.263±0.227	170.0±6.6	174.5±7.5	162.3±6.1
Rep 4	0.273±0.211	0.246±0.200	0.289±0.242	172.1±6.3	162.8±6.7	162.9±6.5
Rep 5	0.295±0.220	0.251±0.195	0.286±0.236	163.8±6.7	165.1±6.6	163.9±6.8
Rep 6	0.272±0.207	0.247±0.195	0.286±0.228	167.3±6.5	162.5±6.3	159.9±7.4
Rep 7	0.286±0.225	0.246±0.183	0.273±0.237	164.0±6.1	160.9±6.5	160.3±6.1
Rep 8	0.255±0.191	0.241±0.165	0.258±0.215	163.1±6.1	160.8±6.8	163.1±6.2
Rep 9	0.256±0.179	0.238±0.186	0.264±0.214	160.8±6.4	158.3±7.6	167.9±6.2
Rep 10	0.253±0.165	0.236±0.179	0.279±0.209	163.1±6.3	158.8±7.6	162.5±6.1

** *MDF statistical difference from Rep. 5-10 ($p<0.001$);* ## *MDF statistical difference from Rep. 8-10 ($p<0.01$).*

Table 1. Root-mean square (EMGrms) and median frequency (MDF) of extensor digitorum muscle from dominant hand; during the 3 conditions, 10 repetitions each condition.

	Flexor Digitorum Muscle					
	EMGrms (mV)			MDF (Hz)		
	Control	WBV+AV	AV	Control	WBV+AV	AV
Rep 1**	0.213±0.017	0.211±0.018	0.233±0.027	151.0±4.8	154.5±7.5	157.9±7.0
Rep 2##	0.241±0.022	0.227±0.019	0.250±0.025	146.3±5.6	143.7±5.9	148.0±6.0
Rep 3	0.243±0.021	0.233±0.020	0.247±0.022	140.0±4.6	147.9±6.3	144.7±5.7
Rep 4	0.251±0.024	0.226±0.018	0.256±0.026	139.6±7.1	140.1±6.1	138.5±5.7
Rep 5	0.244±0.023	0.245±0.024	0.255±0.027	131.7±4.7	132.7±5.4	136.0±6.8
Rep 6	0.246±0.022	0.233±0.021	0.263±0.029	128.2±4.9	131.4±6.2	137.6±5.4
Rep 7	0.248±0.022	0.242±0.019	0.277±0.029	131.7±5.5	137.7±7.9	133.2±5.5
Rep 8	0.247±0.025	0.242±0.023	0.242±0.026	122.6±5.1	128.9±6.6	128.7±6.4
Rep 9	0.244±0.023	0.236±0.022	0.262±0.029	122.1±5.0	124.4±6.4	131.6±6.6
Rep 10	0.229±0.023	0.230±0.023	0.236±0.024	124.3±5.6	131.5±7.2	128.4±6.4

*** MDF statistical difference from Rep. 2-10 (p<0.001); ## MDF statistical difference from Rep. 9.*

Table 2. Root-mean square (EMGrms) and median frequency (MDF) of flexor digitorum muscle from dominant hand; during the 3 conditions, 10 repetitions each condition.

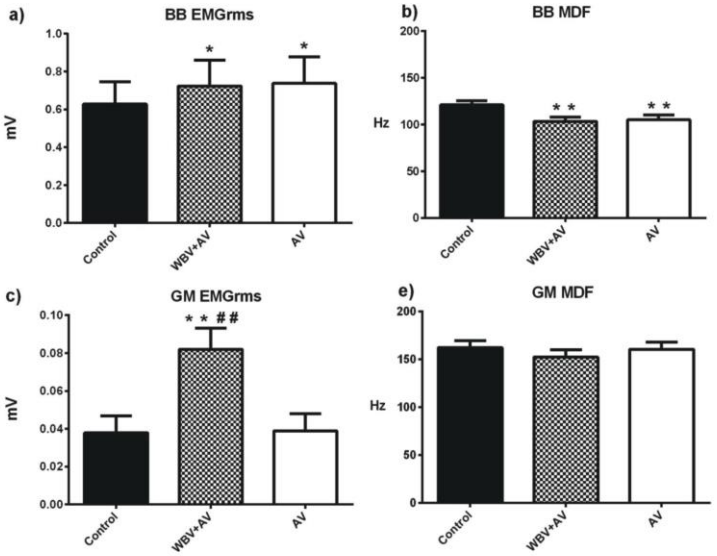

Figure 3. EMG from muscles near vibratory focus. WBV+AV, Whole body vibration and arm vibration; AV, arm vibration; BB, biceps brachii; GM, gastrocnmeius medialis; EMGrms root mean square MDF, median frequency. *Diffencies from Control condition, ($p<0.05$). **Difference from Control condition ($p<0.001$). ##Difference from Control and AV, respectively ($p<0.001$).

observed with the MDF, with a condition effect observed between the Control condition and the WBV+AV and AV ($p<0.001$; $\eta^2=0.521$) indicating that arm vibration produced a decrease in the frequency of muscle activation in muscles near the application of vibration (Figure 3b). The WBV+AV condition showed a statistical significant increase in the EMGrms of the GM ($p<0.001$; $\eta^2=0.596$) compared with Control and AV, indicating that muscles near the vibratory application experience an increase in the amplitude of muscle activation (Figure 3c). Post hoc comparisons for EMGrms and MDF values during each repetition are presented in Table 3 (BB) and Table 4 (GM).

	Biceps Brachii Muscle					
	EMGrms (mV)			MDF (Hz)		
	Control	WBV+AV	AV	Control	WBV+AV	AV
Rep 1**	0.613±0.076	0.650±0.090	0.725±0.088	126.7±4.4	114.8±4.9	112.2±5.5
Rep 2	0.640±0.096	0.742±0.116	0.766±0.095	127.4±4.7	104.7±5.1	107.2±5.6
Rep 3	0.687±0.097	0.754±0.108	0.786±0.100	123.9±4.8	103.2±5.1	106.8±5.7
Rep 4	0.625±0.082	0.754±0.104	0.781±0.103	121.2±4.9	104.3±4.3	106.0±5.6
Rep 5	0.604±0.083	0.794±0.113	0.751±0.093	120.6±4.4	100.2±4.1	104.1±5.7
Rep 6##	0.697±0.095	0.724±0.097	0.782±0.103	119.3±4.6	101.5±4.8	101.5±5.1
Rep 7	0.633±0.086	0.722±0.103	0.714±0.092	119.2±4.6	101.7±4.2	103.2±5.2
Rep 8	0.612±0.080	0.727±0.088	0.724±0.082	119.1±4.6	101.3±4.9	103.8±5.0
Rep 9	0.602±0.082	0.681±0.091	0.681±0.087	117.3±5.0	101.1±4.5	102.3±4.8
Rep 10	0.565±0.087	0.688±0.084	0.667±0.093	116.0±3.8	99.7±4.9	104.0±4.6

*** MDF statistical difference from Rep. 5-10 (p<0.001); ##EMGrms statistical difference from Rep. 9 (p<0.001).*

Table 3. Root-mean square (EMGrms) and median frequency (MDF) of biceps brachii muscle from non-dominant hand; during the 3 conditions. 10 repetitions each condition.

	Gastrocnemius Medialis Muscle					
	EMGrms (mV)			MDF (Hz)		
	Control	WBV+AV	AV	Control	WBV+AV	AV
Rep 1	0.029±0.005	0.070±0.011	0.027±0.005	170.1±7.4	148.5±6.8	161.6±6.7
Rep 2	0.032±0.006	0.078±0.011	0.032±0.006	166.4±7.4	154.1±6.7	161.3±6.3
Rep 3	0.033±0.006	0.076±0.010	0.032±0.006	164.5±8.3	154.1±7.6	163.5±7.3
Rep 4	0.036±0.008	0.078±0.009	0.043±0.009	156.1±6.3	158.6±7.3	163.8±7.0
Rep 5	0.036±0.009	0.081±0.011	0.037±0.008	159.7±7.0	149.1±7.8	157.0±7.1
Rep 6	0.044±0.012	0.078±0.009	0.063±0.023	166.4±8.0	146.8±7.0	156.0±8.1
Rep 7	0.038±0.008	0.088±0.010	0.035±0.007	166.7±7.2	150.6±8.1	156.5±7.1
Rep 8	0.039±0.007	0.092±0.015	0.038±0.009	161.8±7.7	157.9±8.7	163.9±9.6
Rep 9	0.037±0.009	0.091±0.013	0.042±0.008	154.0±7.3	153.8±8.0	162.3±8.6
Rep 10	0.057±0.021	0.092±0.016	0.041±0.008	157.8±8.0	152.0±7.6	160.4±6.8

Table 4. Root-mean square (EMGrms) and median frequency (MDF) of gastrocnemius medialis muscle from dominant hand; during the 3 conditions. 10 repetitions each condition.

Discussion

The main finding of the present study was that the vibration platform initiates a decrease in the coactivation of the extensors during one set of repeated hand grip performance while maintaining the maximal voluntary contraction. In contrast, MVC is not affected by WBV+AV or AV. To the best of our knowledge, this is the first study to assess the effects of WBV on upper limbs. Moreover, previous studies have reported effects of WBV during a dynamic[21,26] set of bicep curls[25] and elbow extension[26]. Those findings demonstrated that vibration exposure improves muscle coordination, decreasing the activation of the antagonist muscle without a decrease in the activation of the agonist muscle. In contrast to Mischi and Cardinale[22], in which it was concluded that vibration exposure increased the activation and coactivation of the triceps brachii and biceps brachii during an isometric elbow extension, the present results show a decrease in coactivation of the extensor digital while activation of the digital flexor is maintained during a set of 10 repetitions of isometric hand grip.

Cardinale and Lim[19] noted that the EMG signal of the vastus lateralis reached higher activity during WBV than no vibration application in an isometric muscular performance. Also Ronnestad[11,30] found the same effects during dynamic lower body performance. The present study found higher muscle activity during isometric upper body performance in the biceps brachii and gastrocnemius.

It has been suggested that vibration may result in greater muscle fatigue because it may increase neuromuscular performance earlier in an exercise[31]. In contrast found no increase

in neuromuscular performance earlier in an exercise[3]. That study found an increase in EMGrms of biceps brachii in the vibration conditions, AV and WBV+AV, respectively.

Wirth et al.[32] found an increase in muscle activation due to WBV during static trunk muscle exercises; depending on two factors, namely on the distance from the corresponding muscle to the vibration platform, and on how much the exercise position challenges body balance. In relation to that finding, the current study found an increase on muscle activity, in the biceps brachial and gastrocnemio medialis, muscles with a close proximity to the current application of both AV and WBV+AV.

This study shows no effect on hand grip mean strength with any vibration condition. However, there was an effect on the number of repetitions and the WBV+AV application increased hand grip strength in relation to the AV condition. Some studies have observed no variation in hand grip force with vibration exposure[5,33,34].

Conclusion

In conclusion, the results of this study suggest that the application of WBV+AV acutely increases muscle coordination and decreases the coactivation of digital extensors muscle without any decrease in hand grip strength. Furthermore, the muscle EMG showed increases in activation near the vibratory focus in both upper- and lower-body.

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Artículo III

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Original Article

Hylonome

The addition of synchronous whole-body vibration to battling rope exercise increases skeletal muscle activity

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Abstract

Objectives: To evaluate the effects of performing battling rope exercise with and without the addition of whole-body vibration (WBV) on muscle activity of the leg, trunk, and upper body. **Methods:** Twenty-eight recreationally active university students completed 20-s of battling rope undulation for 6 separate conditions: 1) alternating arm motion no WBV -Alt_NoWBV; 2) alternating arm motion 30 Hz low amplitude WBV -Alt_30 Hz-L; 3) alternating arm motion 50 Hz high amplitude -Alt_50 Hz-H; 4) double arm motion no WBV -Double_NoWBV; 5) double arm motion 30Hz low amplitude WBV -Double_30Hz-L; 6) double arm motion 50 `Hz high amplitude -Double_50 Hz-H. Electromyography (EMG) was measured for the gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis (VL), rectus abdominis (RA), multifidus (MF), biceps brachii (BB), and triceps brachii (TB) muscles. **Results:** The double arm motion during undulation resulted in greater ($p<0.05$) muscle activity in the VMO, VL, RA, and MF muscles while the GM was more active during the alternating arm motion. WBV at 50Hz increased EMG in all muscles measured vs NoWBV and the 30 Hz condition. **Conclusion:** These results are the first to demonstrate that the exercise stimulus of performing battling rope exercise can be augmented by completing the exercise while being exposed to WBV from a ground-based platform.

Keywords: Battle Ropes, Undulation Training, Electromyography, Reflex, Vibration Exercise

Introduction

Performing body mass resistive exercises on a whole-body vibration (WBV) platform has become an increasingly popular training modality. The vertical oscillations generated via the ground based platform induce short and rapid changes in skeletal muscle fiber length[1-3], which stimulate reflexive muscle contractions increasing skeletal muscle activity[3-12]. The magnitude of these increases in skeletal muscle activity measured via electromyography (EMG) is dependent on the characteristics of the WBV stimulus (amplitude, size of each deflection; frequency, number of deflections per second) with higher frequencies and amplitude inducing greater muscle activity[6,10,13].

The enhanced skeletal muscle activity increases the metabolic muscle demand as evidenced by increases in oxygen consumption/energy expenditure due to the WBV exposure[14-17], though the magnitude of this increased demand is much less than traditional resistance training[7]. Nevertheless, the potential for the WBV stimulus to augment different exercises being performed on the WBV platform is intriguing, as many researchers and health professionals have sought methods to further increase the training stimulus using WBV platforms.

Recently, we have shown the addition of an unstable surface[18] increased lower body muscle EMG suggesting that exercises performed on the WBV platform could be augmented with exposure to the WBV stimulus. The use of battling ropes is a training modality gaining interest in the fitness industry[19]. Battling rope training has participants vigorously undulate heavy ropes (9-15 m in length and 3-5 cm in diameter) that encircle a fixed object. This undulation creates a series of waves for a set interval typically ranging from 10-30 s. This type of training is a vigorous upper-body exercise resulting in an in-

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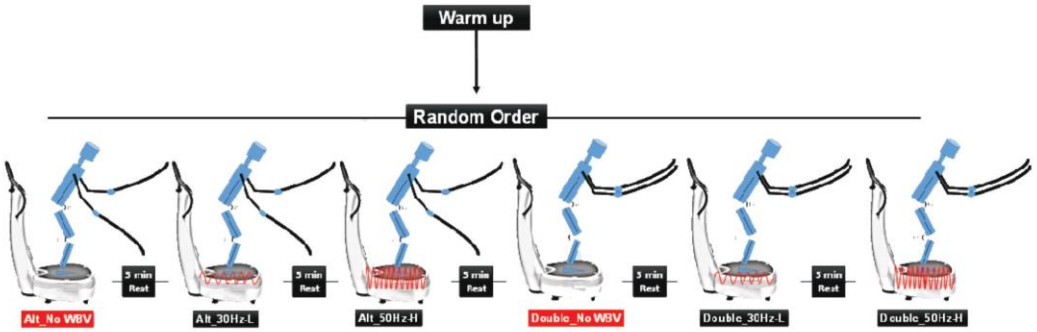

Figure 1. Experiment setup.

tense metabolic workout[20], even greater than several traditional resistance training movements such as squatting, lunges, and deadlifts[21]. As previous research using WBV has demonstrated the addition of WBV to a static and dynamic squat increases both skeletal muscle activity and metabolism, whether the addition of WBV to battling rope exercise augments these effects is effective unknown. Further, there is much interest in the health and fitness realm in time-efficient training. Therefore, the aim of this study was to combine the upper body effects of battling rope exercise with the lower body effects of WBV exposure to evaluate the skeletal muscle activity of battling rope exercise with and without the addition of WBV. Surface electromyography (EMG) was measured in muscles the lower body (vastus lateralis, vastus medialis oblique, gastrocnemius), trunk (multifidus, rectus abdominus) and upper body (biceps brachii, triceps brachii). We hypothesized that the addition of WBV to battling rope exercise would result in an increase in skeletal muscle EMG for all muscles evaluated.

Materials and methods

Experimental design

To investigate the difference in muscle activation between different conditions, a randomized, crossover experimental design was used for this study (all conditions placed in a box, and were picked one by one for each participant). Each participant completed three laboratory sessions in this study (2 familiarization and 1 test session). The experimental protocol began with electrode placement, followed by a standardized warm-up consisting of a 2-min slow jog and 5 dynamic warm-up exercises (10 reps of each exercise for butt kicks, knee to chest, squats, lateral lunges, and inch worms). The test session then had each participant complete one 20-s set of battling rope undulation (Figure 1) for 6 separate conditions followed by 5-min of rest. All sets were performed on the WBV platform and in random order where the 6 different conditions (Figure 1) were: 1) Alternating arm motion no WBV - Alt_NoWBV; 2) Alternating arm motion 30 Hz low amplitude WBV - Alt_30 Hz-L; 3) Alternating arm motion 50 Hz high amplitude - Alt_50 Hz-H; 4) Double arm motion no WBV - Double_NoWBV; 5) Double arm motion 30 Hz low amplitude WBV - Double_30 Hz-L; 6) Double arm motion 50 Hz high amplitude - Double_50 Hz-H).

Participants

Twenty-eight undergraduate students (5 female; 23 male) participated in the study (21.7±1.3 y; 176.7±0.3 cm; 74.0±6.4 kg; mean±SD). All participants were recreationally active but none were involved in a systematic training program for at least 2 months prior to data collection. People suffering from epilepsy, gallstones, kidney stones, neuromuscular or neurodegenerative diseases, stroke, serious heart sicknesses or having an implant, bypass or stent were excluded (3 in total, 1 female). Prior to data collection participants were informed of the requirements associated with participation and provided written informed consent. Participants were encouraged to maintain their dietary, sleeping, and drinking habits during participation in the study (both familiarization trials and experimental session). The research project was conducted according to the Declaration of Helsinki and was approved by the University Review Board for use of Human Subjects.

Battling rope exercise

All participants used a nylon rope 15 m long, weighing 11.2 kg, and 3.8 cm in diameter (O'Live Fitness, Aerobic & Fitness SL, Barcelona, Spain). The rope was anchored at the base of a post, resulting in the participant holding 7.5 m of rope in each hand. Participants began in an athletic position on vibration platform; feet shoulder width apart, knees flexed to 30° with their trunk flexed forward to approximately 45° (Figure 1). These angles were measured via goniometer at the beginning of the bout and participants were asked to maintain these angles during the bout. Participants held the ends of the rope with a neutral grip, with the arms straight and relaxed at their side.

During the alternating arm motion, participants moved their arms up and down in an asynchronous (alternating) fashion (i.e. right arm first, then as right arm was returning to the starting position the left arm began; Figure 1). When performing the double arm motion, participants moved both arms up and down synchronously (at the same time) continuously (Figure 1). Participants were instructed to move their arms as fast as possible and were coached to use minimal lower body and trunk movement as to generate the waves primarily through shoulder flexion when raising the ropes, and shoulder extension when crashing the ropes to the floor. Participants were instructed to have their entire foot in constant contact with the platform with feet spaced shoulder wide apart. All participants maintained a 30°-knee flexion during the exercise.

Vibration equipment

The vibration stimulus consisted of commercial platform (Power Plate® Next Generation pro 5, Power Plate North America, Northbrook, IL, USA) that produced synchronous (uniform) tri-planar oscillations[22]. The acceleration of the vertical sinusoidal oscillations (z-axis) was measured using a uniaxial accelerometer in accordance with ISO2954 (Vibration meter VT-6360, Hong Kong, China). Vibration platform settings included a frequency of 50 Hz with the peak-to-peak displacement of 2.51 mm (High) or a frequency of 30 Hz with peak-to-peak displacement of 1.15 mm (Low). Measured accelerations were 100.6±0.24 $m \cdot s^{-2}$ (at 50 Hz) and 20.44±0.34 $m \cdot s^{-2}$ (at 30 Hz). During all conditions, subjects wore the same athletic shoes to standardize the damping of the vibration because of the footwear[8].

Surface electromyographic activity (EMG)

Muscle activity of the gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis (VL), rectus abdominis (RA), multifidus muscle (MF) muscles, biceps brachialis (BB), and triceps brachialis (TB) were measured using EMG[4,7,8,23,24] on the dominant limb. Prior to electrode placement, the area was shaved and cleaned with isopropyl alcohol to reduce skin impedance. The electrodes were placed over the midbelly of the muscle parallel to the direction of the fibers according to recommendations by the SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) using adhesive double sided tape[25].

The double differential technique was used to detect myoelectric raw signals. The surface electrodes were connected to a 16-bit AD converter (TrigoTM Wireless System, Delsys Inc., Boston, MA, USA). Raw EMG signals were pre-amplified close to the electrodes (signal bandwidth of 20-450 Hz) and sampled at 4000 Hz and stored on a laptop. EMG data analysis was performed using specific software (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, MA, USA). EMG data was averaged by root mean square (EMGrms) in order to obtain averaged amplitude of the EMG signal. EMGrms were calculated together for eccentric and concentric phases. Moreover, in order to obtain average frequency the signal was averaged by median frequency (EMGmdf) which is a valid measure of the frequency shift associated with muscle fatigue[26]. For data analysis only 15 s of the test conditions were utilized (from 2.5 s to 17.5 s).

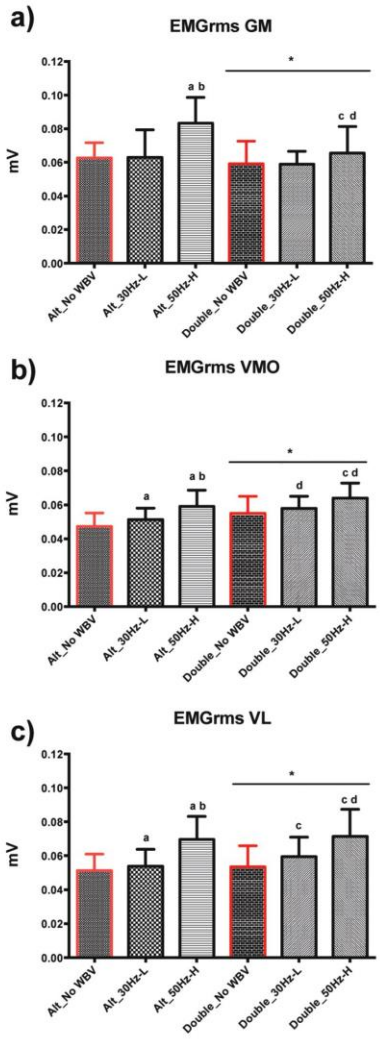

Figure 2. EMGrms activity of the (a) gastrocnemius medialis (GM), (b) vastus medialis oblique (VMO), and (c) vastus lateralis (VL), during 6 experimental conditions. [a] Significantly different than Alt_No condition ($p<0.05$). [b] Significantly different than Alt_30 Hz-L condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$). [d] Significantly different than Double_30 Hz-L condition ($p<0.05$). * Difference from alternate motion at the same condition ($p<0.01$) (n=28).

	GM	VMO	VL	RA	MF	BB	TB
Alt_No WBV	106.8±32.1	78.6±17.1	80.8±14.3	48.9±15.6	57.4±10.6	68.9±10.3	70.1±11.7
Alt_30Hz-L	100.0±29.2	74.8[a]±18.9	76.3±15.4	47.9±15.1	58.3±11.1	68.0±10.7	69.3±12.9
Alt_50Hz-H	103.4±31.6	75.5±16.7	73.8[a]±16.2	48.3±14.0	60.0±8.8	67.5±11.0	69.8±11.8
Double_No WBV	100.0**±32.1	79.6±16.5	79.0±11.9	48.9±10.9	63.9**±13.5	68.4±13.7	66.9*±15.4
Double_30Hz-L	95.7**±28.2	75.7[b]±19.3	74.1±13.4	46.5±11.5	61.2**±13.5	67.1±12.1	66.9*±15.9
Double_50Hz-H	98.2**±28.4	77.3±17.2	72.7[b]±13.6	45.9±10.1	62.3**±12.0	65.8±12.4	68.3*±12.8

a *Significantly different than Alt_No condition ($p<0.05$).* ***b*** *Significantly different than Double_No motion ($p<0.05$).* ***c*** *Significantly different than Double_NO WBV condition ($p<0.05$). *Difference from alternate motion at the same condition ($p<0.05$). ** Difference from alternate motion at the same condition ($p<0.01$) ($n=28$).*

Table 1. EMG median frequency (Hz) activity of the gastrocnemius medialis (GM), vastus medialis oblique (VMO), vastus lateralis (VL), rectus abdominis (RA), multifidus (MF), biceps brachii (BB), and triceps brachii (TB) muscles during 6 experimental conditions.

Arm movements

Frequency of arm movements were measured using a three-axis accelerometer (TrigoTM Wireless System, Delsys Inc., Boston, MA, USA) taped to the wrist of the dominant arm (Figure 5a). The output of the accelerometer allowed synchronization with EMG. Raw accelerometer signals were sampled at 148 Hz and stored on a laptop and data analysis was performed using specific software (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, MA, USA). The frequencies of arm oscillations were recorded for each 20-s exercise condition in the y-axis (anterior/posterior), z-axis (up/down), and x-axis (side/side).

Heart rate

Heart rate average and maximum (beats per min) was recorded beat to beat with a heart rate monitor (Polar RS400, Polar Electro Oy, Kempele, Finland).

Statistical analysis

Data were analyzed using PASW/SPSS Statistics 20.0 (SPSS Inc, Chicago, IL, USA). The normality of the data was checked and subsequently confirmed with the Shapiro-Wilk test. Dependent variables (EMG for each muscle, arm movements in all 3 axes, and heart rate) were evaluated with a repeated measures analysis of variance (ANOVA) on motion x condition. When a significant F-value was achieved, pairwise comparisons were performed using the Bonferroni post hoc procedure. The level of significance was fixed at $p \leq 0.05$. To determine test-retest reliability, intra-class correlation coefficients (ICC's) were calculated for heart rate and arm movements in all 3 axes collected during the familiarization sessions. ICC's were greater than 0.92 indicating a high level of reproducibility in assessing the dependent variables was achieved. Values are expressed as mean±SD and effects sizes were measured by partial Eta square (η^2) to determine the magnitude of the effect independent of sample size.

Results

Gastrocnemius medialis (GM) muscle

A motion x condition interaction effect was noted for GM ($p=0.001$; $\eta^2=0.358$; see Figure 2a). A main effect of the motion was observed indicating a significantly increased EMGrms GM activity during the alternating arm condition compared to double arm motion ($p=0.001$; $\eta^2=0.461$). A main effect of the condition was noted indicating that significantly increased EMGrms GM activity during 50 Hz-H compared to NoWBV and 30 Hz-L ($p=0.001$; $\eta^2=0.680$).

For EMGmdf in the GC (Table 1), during the alternating arm motion the 30 Hz-L stimulus resulted in a lower ($p<0.05$) EMGmdf vs 50 Hz-H and NoWBV. The 50 Hz-H was also lower than NoWBV. There were no differences during the double arm motion.

Vastus medialis oblique (VMO) and vastus lateralis (VL) muscles

A motion x condition interaction effect was detected for VMO ($p=0.030$; $\eta^2=0.122$; see Figure 2b) and VL ($p=0.005$; $\eta^2=0.176$; see Figure 2c). A main effect of the motion was observed indicating that significantly increased EMGrms VMO ($p=0.001$; $\eta^2=0.649$) and VL ($p=0.002$; $\eta^2=0.294$) activity during double compared to alternating arm motion. A main effect of the condition was noted indicating that significantly increased EMGrms VMO ($p=0.001$; $\eta^2=0.827$) and VL ($p=0.001$; $\eta^2=0.805$) activity during 50 Hz-H compared to NoWBV and 30 Hz-L, as well 30 Hz-L compared to NoWBV ($p<0.001$).

For EMGmdf in the VMO (Table 1), the alternating arm motion during 30Hz-L resulted in a lower ($p<0.05$) EMGmdf vs NoWBV. During the double arm motion, the 30 Hz-L condition was lower than the NoWBV condition. For the VL, the 50 Hz-H was lower ($p<0.05$) vs NoWBV and during both the alternating and double arm motions.

Rectus abdominis (RA) and multifidus (MF) muscles

A motion x condition interaction effect was detected for RA ($p=0.001$; $\eta^2=0.610$; see Figure 3a). However, there was no significant motion x condition interaction effect for MF

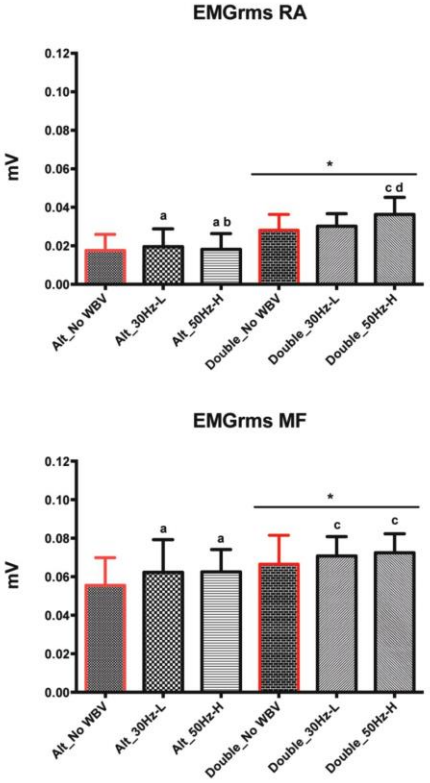

Figure 3. EMGrms activity of the rectus abdominis (RA), and multifidus (MF) muscles during 6 experimental conditions. [a] Significantly different than Alt_No condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$). * Difference from alternate motion at the same condition ($p<0.01$) (n=28).

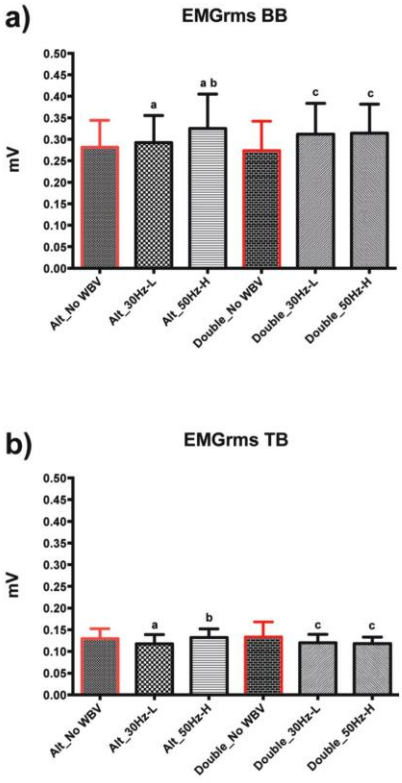

Figure 4. EMGrms activity of the biceps brachii (BB) and triceps brachii (TB) muscles during 6 experimental conditions. [a] Significantly different than Alt_No condition ($p<0.05$). [b] Significantly different than Alt_30 Hz-L condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$) (n=28).

($p>0.05$; $\eta^2=0.003$; see Figure 3b). A main effect of the motion was observed indicating that significantly increased EMGrms RA ($p=0.001$; $\eta^2=0.839$) and MF ($p=0.001$; $\eta^2=0.737$) activity during double compared to alternating arm motion. A main effect of the condition was noted indicating that EMGrms RA ($p=0.001$; $\eta^2=0.600$) and MF ($p=0.001$; $\eta^2=0.354$) activity were increased during 50 Hz-H vs NoWBV and 30 Hz-L, as well 30 Hz-L compared to NoWBV ($p<0.001$).

There were no differences in EMGmdf in the RA (Table 1). For the MF, the alternating arm motion NoWBV condition was lower ($p<0.05$) vs both WBV conditions, and the 30 Hz-L was also lower vs the 50 Hz-H condition.

Biceps brachii (BB) and triceps brachii (TB) muscles

A motion x condition interaction effect was detected for BB ($p=0.001$; $\eta^2=0.213$; see Figure 4a) and TT ($p=0.001$; $\eta^2=0.287$; see Figure 4b). There was no significant main effect of the motion for BB ($p>0.05$; $\eta^2=0.031$) and TB ($p>0.05$; $\eta^2=0.001$). A main effect of the condition was noted indicating that significantly increased EMGrms for BB ($p=0.001$; $\eta^2=0.603$) and significantly decreased for TB ($p=0.001$; $\eta^2=0.369$) activity during 50 Hz-H compared to NoWBV and 30 Hz-L, as well 30 Hz-L compared to NoWBV ($p<0.001$).

There were no differences in EMGmdf in the BB (Table 1). For the TB, the double arm motion resulted in lower EMGmdf ($p<0.05$) than the alternating arm motion in the same condition.

Arm movements

There was no significant motion x condition interaction effect for the *y-coordinate* during battle rope exercise ($p>0.05$; $\eta^2=0.038$; Figure 5b). A main effect of motion was noted indicating that significantly increased frequency of arm movements

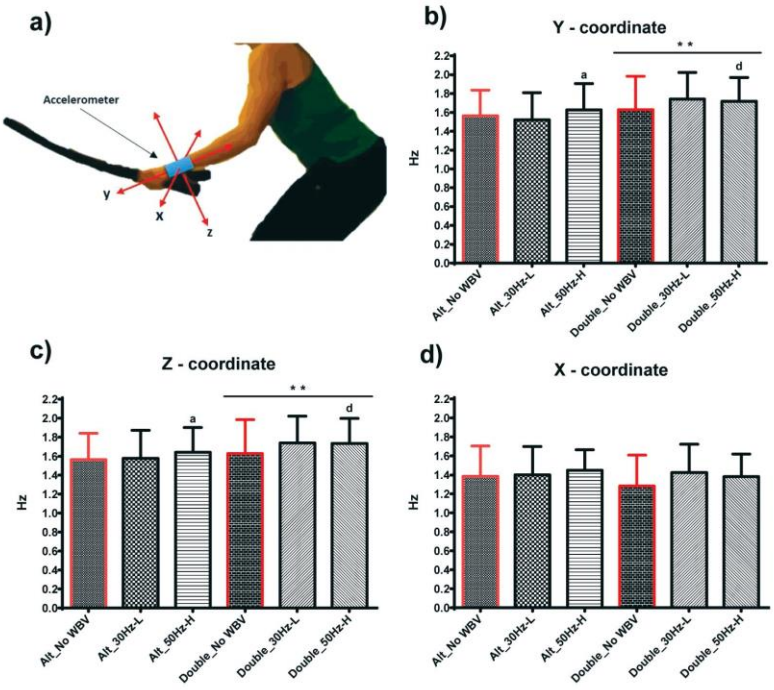

Figure 5. Arm motion (a) frequencies during 6 experimental conditions in the (b) y-coordinate, (c) z-coordinate, and (d) x-coordinate. [a] Significantly different than Alt_No condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$). [*] Difference from alternate motion at the same condition ($p<0.01$) (n=28).

in the *x-coordinate* (anterior/posterior) during the double arm motion vs the alternating arm motion ($p=0.001$; $\eta^2=0.465$). A main effect of the condition was also noted indicating significantly increased frequency of arm movements in the *y-coordinate* during 50 Hz-H compared to NoWBV ($p=0.020$; $\eta^2=0.138$).

There was no significant motion x condition interaction effect ($p>0.05$; $\eta^2=0.050$; Figure 5c). A main effect of motion was noted indicating that significantly increased frequency of arm movements in the *z-coordinate* (up and down) during the double arm motion compared to the alternating arm motion ($p=0.001$; $\eta^2=0.338$). A main effect of the condition was also noted indicating significantly increased frequency of arm movements in the *z-coordinate* during 50 Hz-H compared to NoWBV ($p=0.020$; $\eta^2=0.132$).

There was no significant motion x condition interaction effect for the *x-coordinate* ($p>0.05$; $\eta^2=0.034$; Figure 5d). There was no significant main effect of motion ($p>0.05$; $\eta^2=0.028$) or condition ($p>0.05$; $\eta^2= 0.069$).

Heart rate

There was no significant motion x condition interaction effect of average heart rate ($p>0.05$; $\eta^2=0.012$; Figure 6a) and there were no main effects of motion ($p>0.05$; $\eta^2=0.015$) or condition ($p>0.05$; $\eta^2=0.002$) on average heart rate. There was no significant motion x condition interaction effect on maximum heart rate attained ($p>0.05$; $\eta^2=0.038$). A main effect of motion was noted indicating significantly lower maximum heart rates during the double arm motion vs the alternating arm motion within the same condition ($p=0.048$; $\eta^2=0.137$). A main effect for condition was also noted where the maximum heart rate achieved during the 50 Hz-H condition was greater compared to the NoWBV condition ($p=0.027$; $\eta^2=0.125$; Figure 6b).

Discussion

The current study evaluated the effects of performing battle rope exercise with two different WBV stimuli (30 Hz low vs 50 Hz high). The primary finding is the addition of WBV to battle rope exercise results in an increase in skeletal muscle activity in the lower leg (gastrocnemius), upper leg (vastus medialis oblique and vastus lateralis), trunk (rectus abdominus and multifidus), and arms (biceps brachii and triceps brachii). These results demonstrate that the exercise stimulus of performing battling rope exercise (undulation training) can be

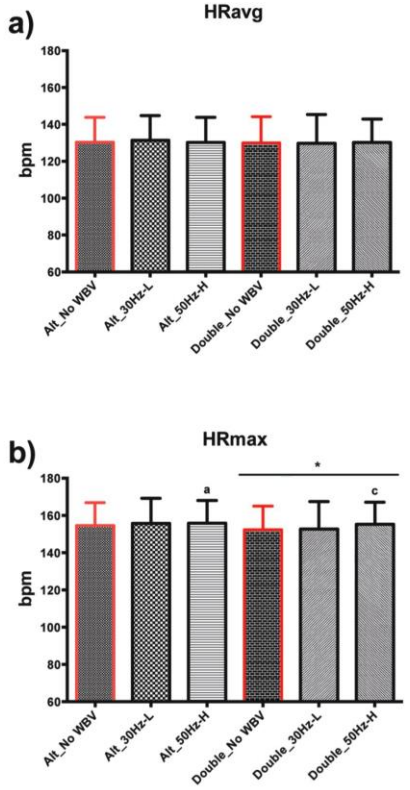

Figure 6. Beats per minute (bpm) heart rate average (a) and maximum (b) during 6 experimental conditions. [a] Significantly different than Alt_No condition ($p<0.05$). [c] Significantly different than Double_No condition ($p<0.05$). * Difference from alternate motion at the same condition ($p<0.05$) (n=28).

augmented by completing the exercise while being exposed to WBV from a ground-based platform.

Battle rope exercise using the alternating arm motion resulted in an increased muscle activity response in the GM of the lower leg compared to the double arm motion suggesting more stabilization in the lower leg is necessary when undulating the battle ropes asynchronously. With the addition of WBV, the 50 Hz stimulus increased muscle activity to a greater extent than the 30 Hz and NoWBV stimuli, while 30 Hz was also greater than NoWBV. This increased in skeletal muscle EMG is a result of the increases skeletal muscle reflexive response via the mechanical vibration oscillations[1-3]. Similar to our previous work, performing different types of exercise on a WBV platform augments the skeletal muscle EMG response[18].

The combination of battle rope exercise and WBV also increased muscle activity in the upper leg (VMO and VL) and trunk muscles (RA & MF). While the double arm motion resulted in greater muscle activity in the upper leg and trunk compared to the alternating arm technique, this response was reversed in the lower leg (GM). These results suggest different muscle activation patterns across the different battle rope undulation protocols. In response to WBV, all muscles had increased skeletal muscle activity in response to WBV compared to NoWBV, while the higher magnitude WBV stimulus (50 Hz, high amplitude) was also higher compared to the lower magnitude WBV condition (30 Hz, low amplitude). These results are inline with previous research demonstrating a WBV-induced increase in skeletal muscle activity[3-8,10,11,13,18,27], and these responses being greater with a higher magnitude (acceleration) stimulus. The increased activation in the MF muscle is similar to our previous study using WBV and an unstable surface[18] though our increase in RA is a novel result of the addition of WBV to battle rope exercise.

In the upper arms (BB and TB), there was no difference between the muscle activity elicited during alternating arm or double arm motions. This is perhaps not surprising as the arms are directly involved in undulating the ropes, whether the movement is asynchronously (alternating) or synchronously (double arm). The addition of WBV still resulted in an increased muscle activity response in the BB with the 50 Hz condition having the greatest EMG. However, the addition of WBV actually resulted in a decrease in TB muscle activity. This suggests that WBV via a ground based platform can alter upper arm muscle activity during upper body exercise (battle rope undulation) which is in line with previous work evaluating upper body EMG during WBV in older adults[9]. Further, the increase in BB and decrease TB EMG suggests a decrease in co-activation of the elbow extensor (TB) while activation of the elbow flexor (BB) is increased (which could affect speed of arm movements discussed below).

While surface EMG has been used quite commonly to measure the muscles response to WBV, it can provide more information than how active the muscle is. The median frequency of the EMG signal divides the frequency spectrum into two equal halves and a shift to lower frequencies are associated with muscle fatigue[26]. The GM and TB muscles had lower EMGmdf during the double arm motion compared to the alternating arm motion suggesting the synchronous undulation exercise protocol was the most fatiguing for these muscles. However, the MF muscle was lower during the alternating arm motion vs the double arm motion. The current results also demonstrate that the different muscles are differentially affected by the different WBV exposures. In the VMO the 30 Hz condition resulted in lower EMGmdf during both motions compared to the NoWBV condition suggesting the 30 Hz condition may result in the most muscle fatigue in the VMO, perhaps due to less reflexive muscle contractions as compared to the 50 Hz condition. However, in the VL muscle, the 50 Hz condition resulted in a lower median frequency compared to NoWBV suggesting a different activation pattern than the VMO in the upper leg. These EMGmdf results suggest that the condition that results in the greatest muscle activity response

generally has decreased EMGmdf suggesting the occurrence of muscle fatigue.

The frequency of arm movements was more rapid in both the *z* and *y* coordinates during the double arm motion compared to the alternating arm motion. Further, the frequency of arm movements was further increased with the addition of the 50 Hz WBV condition vs the NoWBV condition. This increase in arm speed movements with the application of WBV could be due to improved coactivation (increase BB and decreased TB EMG) with WBV exposure allowing a less inhibited arm motion. Further, as the 50 Hz WBV condition had the highest muscle activity for all muscles, except the TB, this data could suggest a benefit to performance (faster arm motion) as there is more active muscle to overcome the weight/resistance of the battling rope. While speculative, the increased EMG with WBV suggests increased cross bridge activity and force production to move an object of the same mass (battle ropes). As the force is increased then it seems possible that the movement velocity would also increase as participants are intending to move the ropes as fast as possible.

There was no difference in average heart rate between alternating arm or double arm motion in the present study. However, maximal heart rate attained during exercise was increased during the 50 Hz condition vs NoWBV in both the alternating arm and double arm motion. Further the maximal heart rates attained during the double arm motion were decreased compared to the alternating arm motion within the same condition. It is presently unclear how peak heart rates attained could be different across conditions without any change in average heart rate, however as peak heart rates were likely attained at the end of each bout, the increase in peak heart rate was likely not attained for a long enough duration to affect average heart rate. Further research exploring these possibilities would be of interest.

In summary, this is the first study to examine the muscle activity response to battle rope exercise performed on a ground-based WBV platform. The current results demonstrate that the muscle activity response while performing battle rope (undulation) exercise can be augmented when the exercise is performed on a ground-based WBV platform. This increase in skeletal muscle activity in the lower leg (gastrocnemius), upper leg (vastus medialis oblique and vastus lateralis), trunk (rectus abdominus and multifidus), and arms (biceps brachii) is caused by an increased skeletal muscle reflexive response via the mechanical vibration oscillations. These increases in muscle EMG were greater with the increased WBV stimuli (50 Hz-H vs 30 Hz-L). For most muscles measured (VMO, VL, RA, MF) the double arm undulation technique resulted in increased skeletal muscle activity compared to the alternating arm motion. However, the GM muscle had increased muscle activity during the alternating arm motion, and EMG was not different between motions for the upper body (BB and TB). In conclusion, these results demonstrate that the exercise stimulus of performing battling rope exercise (undulation training) can be augmented by completing the exercise on a ground-based WBV platform.

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Artículo IV

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Original Article

Effects of whole-body vibration applied to lower extremity muscles during decline bench press exercise

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Abstract

Objectives: To evaluate the effects of whole-body vibration (WBV) on skeletal muscle activity and power performance of the upper body during decline bench press exercise at different loads. **Methods:** Forty-seven healthy young and active male students volunteered. Each performed dynamic decline bench press repetitions with and without WBV (50 Hz, 2.2 mm) applied through a hamstring bridge exercise at three different loads of their 1-repetition maximum (1RM): 30%, 50%, and 70% 1RM. Muscle activity of the triceps brachii (TB), biceps brachii (BB), pectoralis major (PM), and biceps femoris (BF) was measured with surface electromyography electrodes and kinetic parameters of the repetitions were measured with a rotary encoder. **Results:** WBV increased peak power (PP) output during the 70% 1RM condition ($p<0.01$). Muscle activity was increased with WBV in the TB and BF muscles at all loads ($p<0.05$). There were no effects of WBV on BB or PM muscles. **Conclusion:** WBV applied through a hamstring bridge exercise increases TB muscle activity during a decline bench press and this augmentation contributes to an increased peak power at higher loads and increased peak acceleration at lower loads.

Keywords: Vibration Exercise, Kinematics, Power, Acceleration, Muscle Activity

Introduction

Whole body vibration (WBV) as a mode of exercise training has been increasingly more popular in health, physical therapy, rehabilitation, professional sports, and wellness applications because of its effects on the neuromusculoskeletal system[1]. The main benefits effects of the WBV training are increased maximal power output[2,3], strength gains[4], and muscle activity evaluated with surface electromyography (EMG). The majority of the previous studies have focused on the effects of WBV in muscle groups near the vibration stimulus.

While most WBV studies apply vibration in a semi-squat position, it has been postulated based on lower-body examinations that WBV has is greatest effects on muscles most proximal to the generation of the WBV stimulus[5]. Recently the application of WBV to an isometric push-up position (hands directly on platform) acutely increased both growth hormone and testosterone concentrations as well as likely inducing central fatigue[6]. The push-up was chosen as this basic exercise may represent a potent physiological system stressor due to its large muscle volume (trunk + upper arm + lower arm) involvement[7] and the trunk muscles are more strongly activated in the horizontal position compared to the typical standing (half squat) positions during WBV[8]. Other research has demonstrated EMG activity of the biceps brachii and triceps brachii muscles can maximize agonist activation and antagonist activation of these muscles during static vibration exercise[9]. On the other hand, athletes who trained at loads which maximized mechanical power achieved the greatest enhancement in dynamic athletic performance[10] suggesting training with a load that maximizes power output is the best stimulus for further improvements in power[11-13]. Thus, the search for optimal loads for maximizing power is of particular interest for strength and conditioning coaches. Therefore, the purpose of the present investigation was to examine the effects of WBV on skeletal muscle activity and power perfor-

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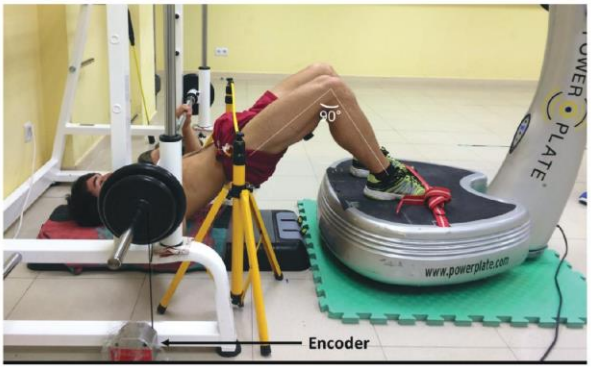

Figure 1. Experimental setup.

mance of the upper body during decline bench press exercise at different loads. We hypothesized that WBV would induce an additional stimulus for neuromuscular system of the upper body and that WBV would evoke greater effects during the higher load conditions.

Materials and methods

Subjects

Forty-seven healthy young and active male students (21.6±1.6 y; 176.0±5.7 cm; 71.9±8.6 kg; mean±*SD*) volunteered for the study. The participants were recreationally active (with some experience in strength training), but none were involved in a systematic training program at the time of data collection or for at least 2 months prior to the study. Exclusion criteria included were diabetes, epilepsy, gallstones, kidney stones, cardiovascular diseases, joint implants, recent thrombosis, and musculoskeletal problems. Prior to data collection all participants were informed of the requirements associated with participation and provided written informed consent. The research project was conducted according to the Declaration of Helsinki and was approved by the University Review Board for use of Human Subjects.

Experimental design

The present study investigated whether a WBV stimulus applied through a hamstring bridge exercise (Figure 1) would benefit muscle performance compared to a control (CTRL) condition during a decline bench press exercise (using a Smith Machine) and whether different loads would induce differences on neuromuscular and power performance. Dynamic decline bench press repetitions were performed under six conditions: 1) low load, 30% 1 repetition maximum (RM) without WBV (CTRL-30); 2) low load, 30% 1RM with WBV (WBV-30); 3) moderate load, 50% 1RM without WBV (CTRL-50); 4) moderate load, 50% 1RM with WBV (WBV-50); 5) high load, 70% 1RM without WBV (CTRL-70); 6) high load, 70% 1RM with WBV (WBV-70).

Familiarization session

One week before the testing sessions, participants attended two familiarization sessions, where one was used to acclimatize participants with the study protocol and the second determined their 1 repetition maximum (RM) using a Smith Machine (Telju, Toledo, Spain). In both sessions, participants performed a standardized warm-up consisting of a 2 min slow jog, 5 dynamic warm-up exercises (10 reps of pull-backs, squats, lateral lunges, hands-to-feet walking, and 2 sets of 10 repetitions of declined bench press with 20 kg load). Following the warm-up, participants adopted the experimental position (hamstring bridge with feet flat on the platform and hands on the barbell; Figure 1). For the purposes of this study, 1-RM is defined as the maximum weight a participant can lift with good form through the full range of motion (lowered the bar until the chest was touched lightly, approximately 3 cm superior to the xiphoid process). Hand spacing was adjusted individually to no more than 1.5 biacromial width and feet remained in contact with the WBV platform in the hamstring bridge during each lift (Figure 1). All 1-RM lifts were administered according to the NSCA guideline[14]. Briefly, participants performed a warm-up with low resistance (50% of anticipated 1-RM) for 8-10 repetitions followed by 3 min rest. Testing was initiated at 70% of anticipated 1-RM, and weight was increased by 5-10 kg until 1-RM was achieved. Each repetition was separated by 3 min of rest and 1-RM was achieved within 5 attempts or less to prevent fatigue.

Experimental session

Participants were fitted with EMG electrodes (detailed below) before completing a standardized warm-up (identical to familiarization session). Following this warm-up, participants completed a maximal isometric contraction in a press position to determine maximal voluntary contractions (MVC) for all muscles. Participants then adopted the experimental position (Figure 1) to perform the six experimental conditions (WBV-30, Control-30, WBV-50, Control-50, WBV-70, and Control-70), while in a hamstring bridge with feet on the WBV platform. All conditions were performed in random order. Three maximum explosive repetitions were performed where participant's were instructed to contract as "hard" and "fast" as possible. Repetitions were performed using a Smith machine (Telju, Toledo, Spain), repetition duration was ~1 s each, and five minutes rest was given between each set.

Vibration equipment

The vibration stimulus was applied via of commercial WBV platform (Power Plate® Next Generation pro 5, Power Plate North America, Northbrook, IL, USA) that produced synchronous (uniform) tri-planar oscillations. The WBV stimulus was applied at a frequency of 50 Hz with 2.2 mm_{p-p} (high) amplitude. These WBV stimulus parameters generated a measured acceleration 99.71 $m{\cdot}s^{-2}$ via the vector sum of the accelerations was measured using a three-axial accelerometer (Vibration Datalogger DT-178A, Ruby Electronics, Saratoga, USA). During all conditions, subjects wore the same athletic shoes to standardize the damping of the vibration because of the footwear[15].

Kinematic parameters

All repetitions were monitored by linking a rotary encoder (Real Speed, Winlaborat V4.20, Buenos Aires, Argentina) to the barbell (Figure 1). The rotary encoder recorded the position of the load plate within an accuracy of 0.1 mm and time events with an accuracy of 0.001 s. Peak power and peak acceleration, (concentric phase) for each repetition was analyzed.

Surface electromyographic activity (EMG)

Muscle activity of pectoral major (PM), triceps brachii long head (TB), biceps brachii (BB), and biceps femoris (BF) was measured using EMG of the dominant side in writing. Prior to electrode placement, the area was shaved and cleaned with isopropyl alcohol to reduce skin impedance. The electrodes (inter-electrode distance=10 mm) were placed over the midbelly of the muscle parallel to the direction of the fibres according to recommendations by the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) project[16].

The double differential technique was used to detect myoelectric raw signals. The surface electrodes were connected to a 16-bit AD converter (TrigoTMWireless System, Delsys Inc., Boston, MA, USA). Raw EMG signals were pre-amplified close to the electrodes (signal bandwidth of 20-450 Hz), sampled at 4000 Hz, and stored on a laptop. EMG data analysis was performed using specific computer software (Delsys EMGworks Analysis 4.0. Delsys Inc. Boston, Massachusetts, USA). The EMG data were averaged by root mean square (rms) in order to obtain averaged amplitude of the EMG signal, and the maximum value of each repetition was selected. This muscle activity was normalized to the EMG signal obtained during the maximal voluntary contraction (MVC).

Statistical analysis

Data were analyzed using PASW/SPSS Statistics 20 (SPSS Inc, Chicago, IL) and significance level was set at P≤0.05. All

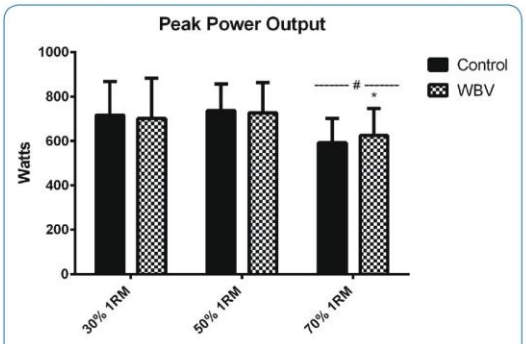

Figure 2. Peak power output during experiment conditions. # Significantly different than 30 % and 50 % 1RM loads (p<0.05).* Significantly different than control condition at the same load (p<0.05).

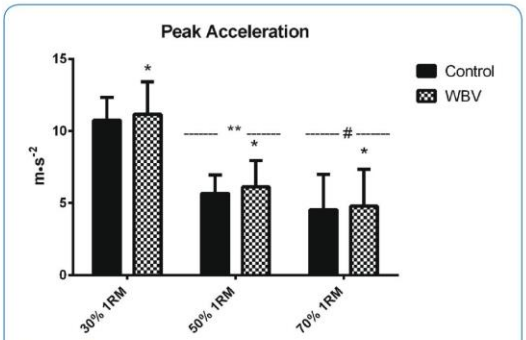

Figure 3. Peak acceleration during experiment conditions. * Significantly different than control condition (p<0.05).** Significantly different than 70 % and 30 % 1RM loads (p <0.05).# Significantly different than 30 % 1RM loads (p<0.05).

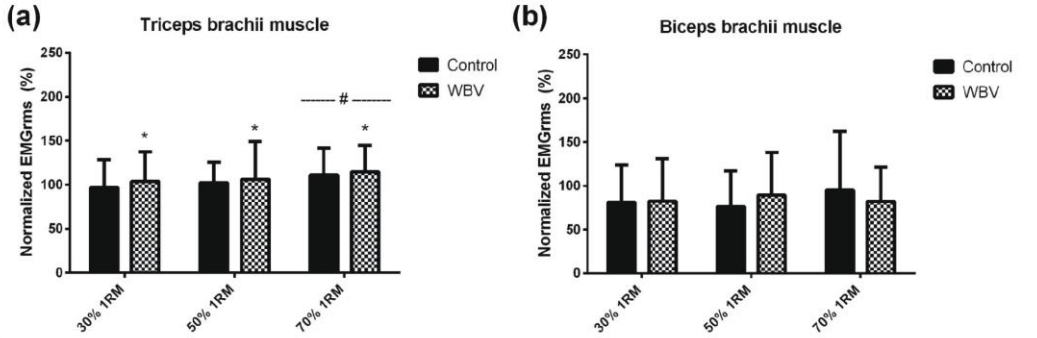

Figure 4. Normalized EMGrms data for triceps brachii muscle (a) and biceps brachii muscle (b). * Significantly different than control condition ($p<0.05$). # Significantly different than 30 % and 50 % 1RM loads ($p<0.01$).

the measures were normally distributed, as determined by the Kolmogorov-Smirnov test. Sphericity was tested by the Greenhouse-Geisser method. Dependent variables (peak power output, peak acceleration, EMGrms for TB, BB, PM, and BF) were evaluated with a two-way repeated measures analysis of variance (ANOVA) on condition x load. Where significant F-values were achieved, pairwise comparisons were performed using the Bonferroni post hoc procedure. Effect size statistic, η^2, was analyzed to determine the magnitude of the effect independent of sample size. From the two familiarization trials, intra-class correlation coefficients were calculated for each dependent variable to determine test-retest reliability, obtaining values always greater than 0.92 (peak power output ICC: 0.94, peak acceleration ICC: 0.94, and EMGrms ICC: 0.93). Values are presented as means±standard deviation (SD).

Results

Kinematic parameters

A load x condition interaction effect (Figure 2) was noted for peak of power (PP) output ($p=0.043$; $\eta^2=0.074$). There was a main effect of load indicating higher PP during the 50% vs 30% 1RM loads compared to the 70% 1RM ($p<0.001$; $\eta^2=0.477$). There was a main effect for condition on PP ($p=0.043$; $\eta^2=0.074$).

There was no load x condition interaction ($p=0.922$; $\eta^2=0.002$) effect for peak acceleration (PA; Figure 3). A main effect of the condition indicates PA during WBV was increased vs CTRL ($p=0.013$; $\eta^2=0.142$). A main effect of load was also observed indicating lower PA during 50% and 70% conditions vs 30% 1RM ($p<0.001$; $\eta^2=0.903$).

Surface electromyographic activity (EMG)

For TB EMGrms (Figure 4), there was no condition x load interaction on TB EMGrms ($p=0.904$; $\eta^2=0.003$), though there was a main effect of the condition ($p=0.038$; $\eta^2=0.136$) and load ($p=0.030$; $\eta^2=0.174$). For condition, EMGrms during WBV was higher vs CTRL and for load the 70% 1RM EMGrms was higher vs 30% 1RM and 50% 1RM ($p=0.006$). For BB EMGrms, there was no condition x load interaction ($p=0.091$; $\eta^2=0.075$) and no main effects for condition ($p=0.934$; $\eta^2<0.001$) or load ($p=0.399$; $\eta^2<0.001$).

For PM EMGrms (Figure 5), there was no condition x load interaction ($p=0.121$; $\eta^2=0.059$) and no main effect for condition ($p=0.114$; $\eta^2=0.070$). There was a main effect of load where EMGrms during the 70% 1RM condition was increased vs 50% 1RM and 30% 1RM ($p<0.001$; $\eta^2=0.199$). For BF EMGrms Figure 5), there was no condition x load interaction ($p=0.761$; $\eta^2=0.008$), but there were main effects for condition ($p<0.001$; $\eta^2=0.363$) and load ($p=0.010$; $\eta^2=0.122$). Within condition, BF EMG was higher during WBV vs CTRL. Within load, the 30%1RM condition was lower vs both 50%1RM ($p=0.046$) and 70%1RM ($p=0.051$) conditions.

Discussion

To the best of our knowledge, this is the first study to assess the effects of WBV applied through the legs on dynamic decline bench press performance. The major finding of the present study was that performing dynamic decline bench press exercise with WBV (applied through a hamstring bridge exercise) and a high load (70% 1RM) produced higher peak power values compared to the same exercise condition without WBV. In addition, while peak acceleration was higher at lower loads as expected, it was increased with WBV exposure. These effects of WBV on peak power and peak acceleration are partly explained by increases in triceps brachii muscle activity.

Exposure to WBV consistently demonstrates increases in lower body skeletal muscle activity while in a standing

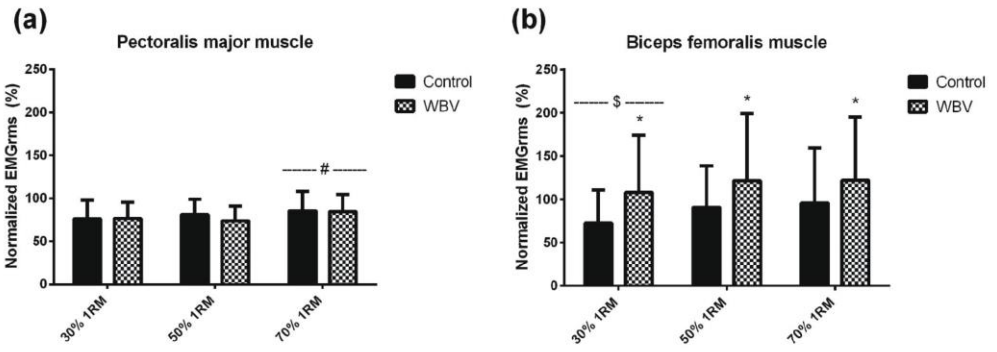

Figure 5. Normalized EMGrms data for pectoral major muscle (a) and biceps femoralis muscle (b). * Significantly different than control condition ($p<0.001$). # Significantly different than 30 % and 50 % 1RM loads ($p<0.01$). $ Significantly different than 50 % and 70 % 1RM loads ($p<0.01$).

position on a WBV platform[15,17-20]. While increases in upper body muscle activity are less studied, we have recently demonstrated that exposure through the feet can benefit upper body exercises[21]. The current data extend these effects to WBV augmentation of decline bench press performance with WBV applied through the feet during a hamstring bridge exercise. While there was no effect of WBV during the lower loaded conditions (30% and 50% 1RM), the benefit of WBV during a higher loaded condition such as 70% 1RM is consistent with previous research on loaded WBV exercise 5, which demonstrated no effect of adding a light load (30% of body mass, ~25 kg) load during dynamic squatting. This may suggest the heavy load is increasing the sensitivity of Ia afferents in muscle spindles due to the preceding level of muscle activity[22,23].

Peak acceleration was also affected by WBV exposure. The increased muscle activity is likely contributing to the participants being able to lift the load faster. This increased muscle activity may represent increased muscle fibre activation, which increases the muscles ability to produce force. Other potential factors explaining why WBV exposure would increase peak acceleration include: decreased motor unit recruitment thresholds[24] resulting in an increased activation of the motor unit pool[25], and neural modifications to cortical and spinal areas responsible for excitatory responses during voluntary contractions[26-28]. While an increased motor unit synchronization is attractive possibility, previous research suggests it does not translate to increases in muscle strength[29]. Nevertheless, the level of contribution from the central nervous system remains speculative and requires further investigation.

The increase in triceps brachii muscle activity is in line with the abovementioned increases in peak power and acceleration with WBV exposure. The TB is a prime mover muscle for the decline bench press and increase in its muscle activity would be expected to contribute to increases in dynamic decline bench press performance. Interestingly, the current data also suggest that exposure to the TB muscle through a hamstring bridge with feet on the WBV platform is successful in transmitting the WBV stimuli to the upper body and still derive benefit. Further to the TB data, there was no effect of condition or load on biceps brachii muscle activity. This could be expected, as the BB is not a primary mover for the decline bench press. However, as the tonic vibration reflex stimulated by the WBV stimulus is likely responsible for the increase in TB muscle activity[30,31], this observation of no increase in BB activity suggests there is also no increased co-inhibition of antagonist muscles occurring. This decreased co-inhibition could also contribute to the improved peak power and acceleration.

With the increase in TB muscle activity, it is somewhat surprising that the pectoralis major muscle did not demonstrate an increase in EMG. As the PM muscle is the main primary mover muscle during a decline bench press, the demonstrated improvement in bench press performance would likely be mediated through this muscle. There are several potential reasons for the lack of activation. Perhaps the effect of WBV was inconsistent in this muscle resulting in a variation skewing the results (Type II error). The anatomical arrangement of the PM (fan-shaped) compared to the more longitudinal arrangement of the TB may also play a role in this lack of effect. Further, as the increase in power and acceleration with WBV exposure was not very large, our current data demonstrate the TB muscle response to WBV may be sufficient to mediate this response. It is also possible that the location of the EMG electrode over the mid-belly of the PM muscle could play a role in the lack of activation as a decline bench press would activate the lower portion of the PM.

The use of the hamstring bridge exercise to apply the WBV stimulus during a decline bench press was a novel aspect of the current study. The increases in biceps femoris muscle

activity were expected due to its close proximity to the vibration stimulus and that the feet were in direct contact with the platform. Similar to the increase in quadriceps muscle activity during static and dynamic squatting seen in previous WBV research[15,17-19], our data are the first to our knowledge to demonstrate WBV during the hamstring bridge results in increased BF muscle activity. These results suggest the use of the hamstring bridge exercise with WBV applied through the feet as a multi-joint stimulus that increases both lower body (hamstrings) and upper body (triceps brachii) muscle activity and resultant improvements in peak power and acceleration.

Despite the large number of participants and repeated measures design, there were still several limitations of the present study. First, the intensity of the decline bench press was of low- to moderate-intensity (30-70% 1-RM) and future research should consider high-intensity loads (>80% 1-RM). Second, while the location of the electrodes followed standardized procedures, locations of the surface EMG electrodes on the TB and PM muscles may have affected the results and subsequent interpretation.

In summary, this study demonstrates that WBV applied through a hamstring bridge exercise increases triceps brachii muscle activity during a decline bench press and this augmentation contributes to an increased peak power at higher loads and increased peak acceleration at lower loads. This suggests decline bench press exercise benefits from WBV exposure, which could be important in training and athletic environments. To our knowledge, this is the first study to assess the effects of WBV applied through the legs on dynamic decline bench press performance.

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Artículo V

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Original Article

Cross transfer acute effects of foam rolling with vibration on ankle dorsiflexion range of motion

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Abstract

Introduction: Foam roller is a device used as a massage intervention for rehabilitation and fitness performance. **Objective:** To examine the effects on the ankle dorsiflexion mobility of the foam roller as well as the combination of foam roller and vibration applied to the ankle plantarflexors muscles, and to observe the possible cross-effect. **Methods:** Thirty-eight undergraduate students participated in the study (19 males and 19 females). This study investigated. Three conditions (3 sets of 20 s) were performed in a randomized order (independent variables): 1) foam roller (Roller), 2) foam roller and vibration (Roller+VIB), and 3) no foam roller or vibration (Control). to determine whether of foam roller with or without vibration would benefit ankle dorsiflexion mobility. Ankle dorsiflexion ROM and plantar flexor were measured in both legs before and immediately after the treatment. **Results:** A cross-effect was found in the non-stimulated leg. There was a significant effect on ankle mobility of Roller and Roller+VIB conditions (6% and 7%, $p<0.001$). **Conclusion:** Foam roller massage and vibration stimulus' foam roller massage increase ankle mobility producing a cross-effect.

Keywords: Massage, Self-Miofascial Release Mobility, Strength

Introduction

Foam rolling is a popular technique used as a self-massage intervention. The principal use of this type of self-massage release is for rehabilitation and fitness performance to enhance myofascial mobility. Previous evidence has reported foam rolling can increase joint range of motion (ROM)[1] and improve the recovery process[2]. Regular, intense or unaccustomed exercise can evoke a possible pain effect on muscle, where foam rolling has been shown to reduce delayed onset muscle soreness (DOMS)[3] and decrease perceived fatigue[4]. Currently, there are two commercial foam rollers that have been used in previous research, such as the standard model (15.24 cm x 91.44 cm)[2-8] and half size model (15.24 cm x 45.72 cm)[9] where body weight of the individual is used to apply pressure to soft tissues during the rolling motion[10].

Foam rolling is an effective intervention for enhancing joint range of movement in pre- and post-exercise muscle performance10 but currently there is no defined program of foam roller massage due to the heterogeneity of methods reported in previous studies[10]. To increase ROM various methods of stretching are often employed, such as, static, ballistic, and dynamic stretching as along with proprioceptive neuromuscular facilitation[11]. Static stretching is commonly utilized, however when it is implemented as part of warm up, muscular power and performance decreases[12]. If the myofascia is injured, inactive, or inflamed it can restrict ROM and decrease strength and endurance[1]. Currently there is a plethora of practitioner-partnered techniques to treat fascia such as, osteopathic soft-tissue manipulations, structural integration, massage, muscle energy techniques, and Graston[13]. However, an alternative technique that is independent of a practitioner, is self-induced myofascial release, which can be facilitated with a foam roller or roller massager[11]. In several studies foam rolling has demonstrated an increase in ROM measure[8,13-14].

Another training method that has been popular over the last decade is vibration therapy. The vibration stimulus can be applied directly to the muscle or tendon or indirectly to the whole body where the stimuli enters via the feet while standing on a vibration platform[15]. The use of direct vibration

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therapy as a recovery modality to reducing muscle soreness and fatigue is gaining a lot of interest. For instance, applying direct vibration therapy to elbow flexors following strenuous eccentric exercise has been shown to attenuate muscle soreness and improve ROM[16]. However, little is known about the efficacy of combining foam roller with vibration to enhance ROM improvements. In most instances unilateral foam rolling occurs, however there is paucity of information whether unilateral exposure to foam rolling can improve performance of the other leg. Previous studies have observed strength changes in the non-trained limb[17] of knee extensors[18-20] and elbow flexors[21,22]. Likewise, Shima et al.[23] found that after 6 weeks training of single leg calf raises and plantar flexion a cross-effect was apparent in ankle plantarflexors of the contralateral leg.

Currently, there is a lack of knowledge about the use of concurrent vibration and roller and its efficacy to elicit a cross-effect on the contralateral leg to improve ROM. Therefore, the main purpose of this study was to examine the effects on the ankle dorsiflexion mobility of the foam roller as well as the combination of foam roller and vibration applied to the ankle plantarflexors muscles, and to observe the possible cross-effect. We hypothesized that vibration combined with foam roller would induce an increase in ankle dorsiflexion mobility for the leg that receives the stimulus and the contralateral limb.

Materials and methods

Experimental design

This study investigated whether 3 sets of 20 s of foam roller with or without vibration would benefit ankle dorsiflexion mobility. Ankle dorsiflexion ROM and plantar flexor were measured in both legs before and immediately after the treatment. Three conditions were performed in a randomized order (independent variables): 1) foam roller (Roller), 2) foam roller and vibration (Roller+VIB), and 3) no foam roller or vibration (Control). All treatment conditions were applied to the dominant leg and were separated by at least 48 hours and were conducted at the same time of day to take into account for daily biorhythms. The preference for kicking a ball was the criteria to determine participant's dominant leg.

Participants

Thirty-eight undergraduate students participated in the study, 19 females (19.5±7.2 y, 167.8±0.1 cm, 59.2±2.2 kg) and 19 males (21.8±2.7 y, 178.9±0.1 cm, 73.7±9.1 kg). One female and 5 males indicated left leg dominance. Each participant performed all 3 conditions to minimize inter-individual variance in muscle response. All participants were recreationally active but none were involved in a systematic exercise-training program at the time of data collection or for at least 2 months prior to the study. Prior to data collection participants were informed of the requirements associated with participation and provided written informed consent.

Figure 1. Ankle ROM test.

Exclusion criteria were diabetes, epilepsy, gallstones, kidney stones, cardiovascular diseases, joint implants, recent thrombosis, as well as musculoskeletal problems. Participants were encouraged to maintain their dietary, sleeping, and drinking habits during the study. Two to three days before the testing sessions, participants attended one familiarization session. The study was conducted according to the Declaration of Helsinki and was approved by the University Review Board for use of Human Subjects.

Foam rolling and vibration

A commercial foam roller (Vyper®, Hyperice, Irvine, USA) with three different vibration frequencies that produced uniform oscillations was used in the current study. The roller was set at the medium setting with the following parameters; a frequency of 49 Hz with and an amplitude of 1.95 mm (distance from peak-to-peak). Using a three-axial accelerometer (Vibration Datalogger DT-178A, Ruby Electronics, Saratoga, USA) with 60 kg on foam roller it generated an acceleration of 92.6 $m \cdot s^{-2}$. This was obtained via the vector sum of the accelerations and data analysis was performed using specific software (Vibration Datalogger DT-178A, Ruby Electronics, Saratoga, USA). During all the conditions, participants did not wear any clothing on the calf or socks.

Ankle ROM test

The ROM of ankle dorsiflexion was assessed using Leg Motion system (Check your MOtion®, Albacete, Spain), which is a portable tool used to measure ankle dorsiflexion during a weight-bearing lunge[24]. Participants were tested before (Pre) and after (Post) for each condition (Figure 1). All assessments were conducted by the same researcher according to the reliability protocol established by Ortega and colleagues[25]. The leg motion ankle dorsiflexion test was preceded by two warm-up attempts with the third attempt recorded. Each participant started with their hands on their

Figure 2. Foam rolling technique.

hips, where the assigned foot was located on the middle of the longitudinal line just behind the transversal line on the platform. The contralateral foot was positioned to the side of the platform. While maintaining this position, participants were instructed to perform a lunge where the knee was flexed with the goal of making contact between the anterior knee and the perpendicular metal stick. When participants were able to maintain heel and knee contact, the metal stick was progressed away from knee. The distance achieved was recorded in centimeters. Three trials were performed for each ankle (dominant and non-dominant) with 10 seconds of passive recovery between trials. The third value from each ankle was selected for subsequent analysis of weight-bearing dorsiflexion ROM (DF ROM)[26].

Maximal voluntary isometric contraction

A custom-made ankle strength device was used to measure maximal voluntary isometric contraction (MVIC) plantarflexion (PF) and dorsiflexion (DF) force. Participants were seated on a chair, with their trunk, thighs, lower thighs, and foot fastened to the chair and the force meter device. The DF and PF were calculated as the tensile and compressive force of a strain gauge (Winlaborat V4.20, Buenos Aires, Argentina).

Participants then performed three trials at maximal effort of 4 seconds with a 1-min rest period between trials to minimize muscle fatigue. The average of three measures was calculated. DF ROM, PF, and DF were re-measured on a different day to determine the test-retest repeatability of such measurements, by calculating intraclass correlation coefficient (ICC).

Treatment protocol

Participants began all experimental sessions with a warm-up consisting of 10 bilateral heel rises at a duration of one second to rise the heels and 1 second to for the heels to make contact with the ground. Each participant performed three separate conditions in a randomized order in barefoot. 1) Roller (roller only), 2) Roller+Vibration (roller and vibration at 32 Hz), 3) Control (sitting on a chair). The Roller consisted of 3 sets of 20 seconds in duration with a 10-second rest between sets[27]. Thus, the volume of work performed in the Sham condition was equalized. Foam rolling was performed in a seated position with the legs extended and the foot relaxed as shown in Figure 2. Participants were instructed to use their arms to propel their body back and forward, from popliteal fossa to Achilles tendon, in a smooth and continuous motion of 3 seconds forward and 1 second backward and then vice versa from Achilles tendon to popliteal fossa. The first set was performed on the lateral side of the triceps sural, the second set on the center and the third set on the medial side of the triceps sural. They were also instructed to exert as much pressure on the dominant leg, whilst the contralateral leg was placed on a body-mass scale to avoid exerting additional pressure. The measures of DF ROM, PF, and DF were made before and immediately (less than 10s between condition and measure) after the treatment in both legs in a randomized order.

Statistical analysis

Data were analyzed using PASW/SPSS Statistics 20 (SPSS Inc, Chicago, IL) and significance level was set at $P \leq 0.05$. All the measures were normally distributed, as determined by the Kolmogorov-Smirnov test. Sphericity was tested by the Greenhouse-Geisser method.

Dependent variables (DF ROM, PF, and DF) were evaluated with a two-way repeated measures analysis of variance (ANOVA) of condition x time. Where significant F values were achieved, pairwise comparisons were performed using the Bonferroni post hoc procedure. Effect size statistic, η^2, was analyzed to determine the magnitude of the effect independent of sample size. Values are presented as mean ± standard deviation (SD).

Results

The ICCs of DF ROM, PF, and DF were 0.98, 0.87 and 0.89, respectively.

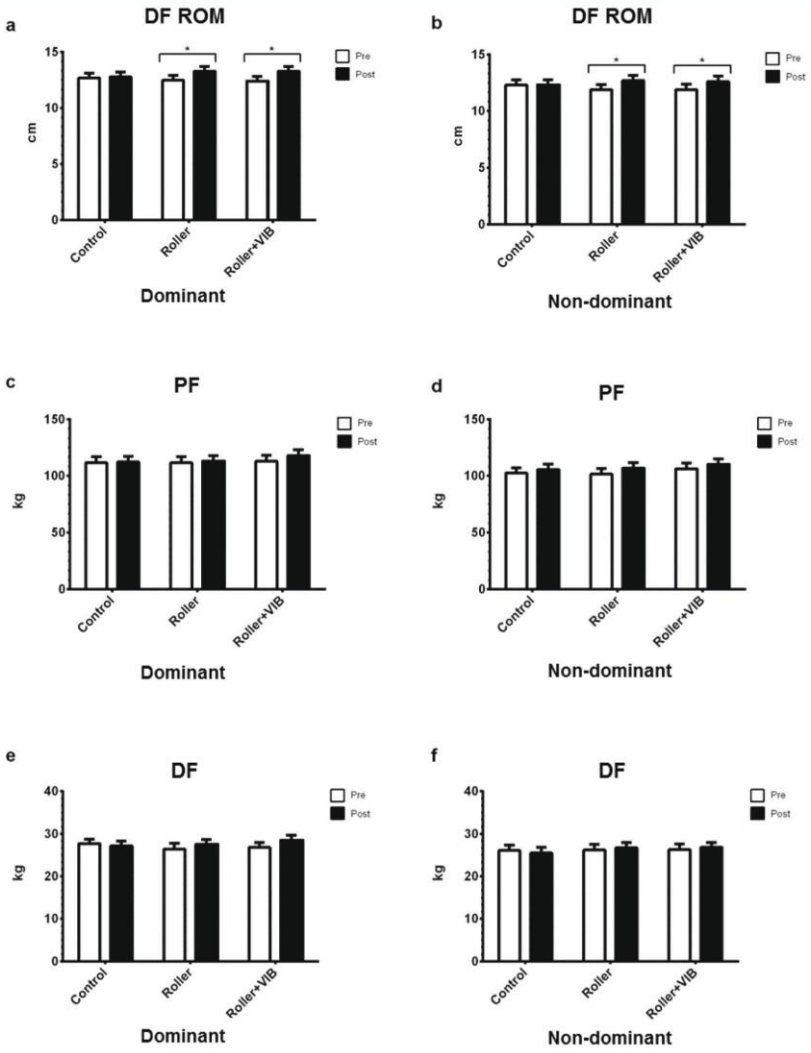

Figure 3. a & b - DF ROM of dominant and non-dominat limb; c & d - PF of dominant and non-dominat limb; e & f - DF of dominant and non-dominat limb of control, roller and roller + vib conditions. DF ROM = dorsiflexion range of motion; PF = plantarflexion force; DF = dorsiflexion force.

Ankle ROM

Ankle dorsiflexion ROM was higher in Roller and Roller+VIB compared to Control for both legs ($p<0.001$; $\eta^2=0.394$). After Roller condition, dominant leg and non-dominant leg reported a 6% of improvement of ankle dosrsiflexion ROM, while for Roller+VIB condition dominant leg increase 7% and non-dominant leg 5% (Figure 3a and 3b). A significant time effect ($p<0.001$; $\eta^2=0.762$) was observed in all conditions, and a leg effect was found ($p<0.05$; $\eta^2=0.099$) (Figure 3a and 3b).

Maximal voluntary isometric contraction

There was no significant difference in the PF (Figure 3c and 3d) or DF (Figure 3e and 3f) between conditions ($p>0.05$).

Discussion

The main finding of the present study was foam roller or foam roller and vibration stimulus of the dominant calf muscle elicited an increase in ankle dorsiflexion ROM in the treated and contralateral limb. In contrast, MVIC was not affected by foam roller. To the best of our knowledge, this is the first study to assess the effects of foam rolling with foam roller combined with vibration, as well as the first study to observe the effects of this treatment on the contralateral limb. Moreover, previous studies have reported that foam rolling can have a positive influence on ankle dorsiflexion ROM and it is capable of eliciting cross-over effect on the contralateral limb[9,27].

Pellegrini et al.[28] investigated the acute effect of whole body vibration (WBV, 26 Hz, 4-4.5 mm amplitude) on the voluntary activation of the ankle plantar flexors in healthy young adults and reported that after 5 sets of 1 minute of stretching of the plantar flexors with WBV that plantar flexor force increased. In contrast, the present study found no significant increase in plantarflexor MVIC. Our current results used a higher frequency vibration stimulus (49 Hz) compared to a lower frequency in previous work (26 Hz). Our work also used a different vibration device, a vibration roller versus a vibration platform. However, the methodology may explain the dissonance, in the current study we analyzed isometric muscle action but Pellegrini et al.[28] study used an isokinetic exercise protocol. Furthermore, Harwood et al.[29] revealed that isometric plantar flexor performance decreased immediately following five 60-seconds bouts of WBV (45 Hz, 2 mm amplitude) and as a result of consecutive acute bouts of vibration the authors suggested the Ia pathway was compromised.

In support of the current findings a recent study analyzed the effects of foam rolling on muscle recovery after exercise-induced muscle damage (EIMD), and concluded that foam rolling had no effect on plantar flexor performance, morphology, and oxygenation recovery after EIMD, except for muscle pain pressure threshold[30]. Furthermore, the present findings indicate the Roller increased ankle dosrsiflexion ROM of dominant and non-dominant leg by 6%, while Roller+VIB increased ROM in the dominant leg (7%) and non-dominant (5%). This is similar to 4-10% ROM improvement reported by previous studies of the hamstrings1 and ankle dorsiflexion[31].

However, the additive effect of vibration with foam rolling did not significantly improve ROM compared to foam rolling alone. Additionally, it did not enhance plantarflexion and dorsiflexion isometric strength. Although the foam roller was acting directly on the triceps sural, it is possible that the current rolling duration of 3 seconds forward and 1 sec backward for 20 seconds may have not been substantial for the vibration stimulus to elicit the appropriate responses to enhance muscle performance. Therefore, a higher vibration frequency and amplitude, along with a slower rolling duration may be required to ensure that the additive component of vibration can be realized. Moreover, it is plausible that the force applied during foam rolling may have nullified the additive effect of vibration. Further research is required to determine if an optimal force is required on the muscle group when vibration is combined with foam rolling.

Despite the ROM increase being similar in both conditions (Roller and Roller+VIB) it is difficult to ascertain the mechanism(s) for its improvement, as there may be various aspects that are involved. Without direct evidence it is difficult to substantiate, however one may speculate that changes occurred in the viscoelastic elements of the musculotendinous unit[32,33] and that stretching tolerance of ROM improved[34].

The concept of cross-over effect has been well documented in unilateral resistance training where neural adaptations are the likely mechanism[35] to eliciting changes on contralateral strength[17]. The findings of the present study indicate that ROM was enhanced in the affected and the contralateral limb. This is supported by Jay et al.[36] who reported that following exercise induced DOMS, acute muscle soreness was reduced and pain threshold was increased from 10 minutes from foam rolling the hamstrings of the ipsilateral limb; additionally, there was a tendency of reduced muscle soreness in the contralateral limb. The authors postulate that central pathways may be a potential source to eliciting the cross-over transfer. In contrast, the current results showed that combining vibration with foam rolling had little effect on ROM, therefore it is likely that the participant's force applied to the roller of the ipsilateral limb may have caused a global response of stimulating the mechanoreceptors, which supports the idea of a cross-over effect of the contralateral limb[27].

In conclusion, the present study documents for the first time that foam rolling combined with vibration increases dorsiflexion ROM and a cross-over transfer effect was observed in the contralateral limb. However, the addition of the vibration stimulus with foam rolling did not further increase ROM compared to foam rolling alone. Thus, there seems little benefit of including vibration with foam rolling to increase ROM, however further research is required to determine its prophylactic or therapeutic recovery ability to deter muscle fatigue and accelerate muscle performance.

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