Department of Physical Education and Sport,

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EFFECTS OF DIFFERENT PROTOCOLS OF POST-ACTIVATION PERFORMANCE ENHANCEMENT ON THE RESISTANCE TRAINING PERFORMANCE OF PHYSICALLY ACTIVE MEN

Presented by

Arkaitz Garbisu Hualde

Vitoria-Gasteiz, 2023

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I have never been brilliant studying, but I have never stood not understanding why things happen or how things work. So, when I was taught how to search and filter quality information, I discovered a whole world of knowledge available. Furthermore, when I was proposed to do a thesis, I was excited. The very idea that I could contribute to the knowledge people looks for all around the globe was incredible. I also had to become familiar with the other side of researching, rejection. It was tough at the beginning but clarifying. One of the most important things I have learned during these years is that no matter how convinced you are about something, you can still be completely wrong. These four years have been insane, but I have been surrounded by my family and friends, and I would like to dedicate them some lines before I start my dissertation.

My mom, Idoia Hualde, taught me that patience and being cold-minded are two of the greatest virtues a person can have. Thank you for teaching me that not even the greatest botanist can grow a tree in three days.

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We´ve arranged a global civilization in which most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology.

This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces.

Carl Sagan – The demon-haunted world: science as a candle in the dark

SCIENTIFIC CONTRIBUTIONS

Peer-reviewed publications

Study 1:

Garbisu-Hualde, A., & Santos-Concejero, J. (2021). Post-Activation Potentiation in Strength Training: A Systematic Review of the Scientific Literature. *Journal of Human Kinetics*, *78*(1), 141-150.

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Study 2:

Garbisu-Hualde, A., Gutierrez, L., Fernández-Peña, E., & Santos-Concejero, J. (2023). Intermittent Voluntary Isometric Contractions Effects on Performance Enhancement and Sticking Region Kinematics in the Bench Press. *Journal of Human Kinetics*, *87*(1), 105-117.

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Study 3:

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ABSTRACT

Resistance training has gained notorious popularity over the last years. This increasing interest for strength related sports such as powerlifting, weightlifting or bodybuilding, has increased the number of competitors and coaches. As the main function of coaches is improving their athletes´ performance, several strategies have been studied, as Post-Activation Performance Enhancement (PAPE). PAPE is commonly used as a strategy to improve acute voluntary force production. PAPE and Post-Activation Performance (PAP) should not be confused as they have some key differences: (i) the need for electrically induced confirmation in the case of PAP, and (ii) the potentiation-time profile. In this sense, PAP has a shorter lifespan (~4-5 minutes), while PAPE could last up to 20 minutes. PAPE has gained notorious popularity in power related sports due to its capacity to improve acute rate of force development using different strategies with different muscle contraction regimes as conditioning stimuli. Various load protocols, such as optimal power loads, medium loads and plyometric contractions can be used, and is especially useful when trying to improve performance in submaximally loaded sport tasks as sprinting, jumping or throwing.

Another important factor addressed by coaches when trying to improve performance is Sticking Region. This refers to the region of the lift where it can be failed during training or competition, and it is defined as the region between the initial maximum peak and the first minimum peak in velocity during the propulsive phase of a lift. The reason behind this phenomenon seems to be mechanical disadvantage of the weakest muscle group involved. This region is highly individual as it depends on muscle mass quantity and how it is distributed, the expertise level of the individual in the tested motor pattern, joint form

and bone length. Different strategies have been adopted to face this sticking region, which we can divide in long-term strategies (specific training) and short-term training (where PAPE is useful).

The main purposes of this thesis were: (i) to observe if a strategy to improve performance acutely (i.e., PAPE) is effective over sticking region kinematics and characteristics, (ii) compare different contraction regime-based PAPE protocols and (iii) study if a PAPE protocol can improve resistance training volume.

The thesis commences with a systematic review of the scientific literature, which aimed to determine the ideal combination of Post-Activation Potentiation strategies for an improved strength performance. We conducted a literature search in October 2020 (PubMed and Scopus) for original research articles. After analysing 202 total citations, only studies meeting the following inclusion criteria were included: a) subjects´ age ranged between 18-30 years; b) studies analysed experienced lifters; c) post-activation potentiation was studied in sports with high requirements of the rate of force development; d) the potentiation protocol was conducted with barbell exercises; e) pre- and post-evaluation was done with a resistance exercise, vertical jump or similar (i.e. squat jump, counter movement jump or drop jump). Only peer reviewed studies written in English were selected. Seventeen studies met the inclusion criteria, ten had a level of evidence 1b (good quality randomised control trials) and the remaining 7 had a level of evidence of 2b (individual cohort studies) according to Oxford´s level of evidence scale. According to the results, even if different protocols can be used to achieve post-activation potentiation, it seems that higher intensities induce better performance enhancement. More precisely, it seemed that (i) experienced lifters benefit more than their nonexperienced counterparts, (ii) high intensities bring better results, and (iii) 7-8 minutes rest-intervals seem appropriate.

Based on these results, we tried comparing a different contraction regime-based PAPE protocol with a traditional high-loaded PAPE protocol. The study aimed to analyse the role of a maximal isometric PAPE protocol in performance and its effects on the kinematics of the sticking region compared to a traditional PAPE protocol. For this purpose, twenty-one trained participants (age 26.4 ± 5.4 years) underwent two experimental sessions: an experimental session consisting of a single set and a single repetition in bench press at the 93% of 1RM (which is considered a traditional conditioning activity to induce PAPE) and an isometric experimental session consisting of 15 maximal voluntary isometric contractions in the sticking region of the medium grip bench press lasting 1 second with 1 second rest between contractions. Analysed data included mean propulsive velocity of the pre-sticking region, the first maximum peak in velocity and the first minimum peak in velocity. Only the isometric PAPE protocol improved performance in the pre-sticking region (mean velocity from the start of the lift until the first maximum peak in velocity) ($p < 0.001$; ES = 0.67, moderate effect), velocity in the first maximum peak ($p = 0.005$; ES = 0.71, moderate effect) and in the first minimum peak ($p = 0.025$; ES = 0.38, small effect). Findings in this study suggest that a high intensity isometric PAPE protocol improves sticking region and pre-sticking region kinematics, helping the lifter to overcome the lift. This improvement is evident in the first period of the ascending phase, prior to the sticking region, which helps the lifter to overcome that sticking region. The main enhancement is that the first maximum velocity peak is greater after the isometric conditioning protocol which provides the lifter with a greater impulse to overcome the sticking region. This improved velocity changes sticking region´s velocity-time profile.

As PAPE protocols are commonly used in submaximal loaded tasks or explosive tasks, we tried to test if a PAPE protocol is a useful tool when trying to improve resistance training volume. The last study aimed to analyse the influence of a PAPE protocol on bench press performance in a training set to volitional failure in trained individuals compared to a control condition with no PAPE protocol. Fourteen participants with at least 2 years of resistance training experience (age 24.57 ± 2.7 years; body mass 77.47 ± 12.2 kg; body height 174.21 ± 7.4 cm; medium grip bench press 1 repetition maximum (1RM): 101.6 ± 25.8 kg), of which 14 completed the control protocol and 12 completed the experimental protocol, took part in the study. In the group performing a PAPE protocol, participants performed more repetitions than in the control condition ($p=0.008$; $ES=0.5$, small effect), their last repetition was slower ($p=0.02$; $ES=0.52$, small effect) and presented a higher velocity loss ($p=0.004$; $ES=0.75$, moderate effect). Results in this study suggest that performing a traditional PAPE protocol prior to a set to volitional failure could make the athlete acutely more resistant to fatigue in long-lasting tasks, which could result in a potential way of improving performed volume. The quantity of work performed per session, understood as total number of sets or understood as volume load (sets x repetitions x kilogram) is related to the quantity of gained muscle mass. Thus, if PAPE improves performed number of repetitions until failure, volume load per session would be improved, and so could muscle hypertrophy. It could also be assumed that hypothetic muscle hypertrophy benefits could be due to both, improved mechanical tension of the last repetition and to higher performed repetitions. Nevertheless, the study

was performed with only one set until volitional failure, but the effect of this set and its fatigue on subsequent sets was not tested.

The main conclusion drawn from this thesis was that there is a disconnection between science and practice, as usually used protocols are not effective in the contexts that are used (i.e., maximal strength shows or powerlifting meets). Alternative protocols (as isometric protocols) are more suitable for those situations, as slight improvements in Sticking Region kinematics can be crucial when succeeding a 1RM attempt. Regarding traditional high-loaded PAPE protocols, they should be principally used in submaximal loaded tasks, where combined with an appropriate rest interval can bring clear benefits.

Key words: Post-Activation Potentiation; Post-Activation Performance Enhancement; Sticking Region; Powerlifting; AMRAP; failure; strength training; training volume; isometric strength

RESUMEN

El entrenamiento de fuerza ha ganado una notable popularidad en los últimos años. Este creciente interés por los deportes relacionados con la fuerza, como el *powerlifting*, la halterofilia o el culturismo, ha aumentado el número de competidores y entrenadores. Dado que la función principal de los entrenadores es mejorar el rendimiento de sus atletas, se han estudiado varias estrategias, como la mejora del rendimiento post-activación (PAPE). La PAPE se ha utilizado comúnmente como una estrategia para mejorar la producción de fuerza voluntaria de manera aguda. No deben confundirse los términos PAPE y potenciación post-activación (PAP), ya que existen ciertas diferencias: (i) la necesidad de una confirmación inducida eléctricamente en el caso de PAP y (ii) el perfil de tiempo-potenciación. En este sentido, la PAP tiene una vida más corta (~4-5 minutos), mientras que la PAPE puede durar hasta 20 minutos. La PAPE ha ganado una notoria popularidad en deportes que se basan en la potencia debido a su capacidad para mejorar la tasa de desarrollo de fuerza de manera aguda mediante protocolos que siguen diferentes estrategias. Entre esas estrategias, podemos encontrar protocolos con cargas muy variadas, como cargas óptimas para la potencia (*optimal power load*), cargas medias e incluso protocolos basados en contracciones pliométricas. Estos protocolos de PAPE son especialmente útiles cuando se trata de mejorar el rendimiento en tareas deportivas de carga submáxima, como pueden ser el sprint, el salto o los lanzamientos.

Otro factor importante que tienen en cuenta los entrenadores es la región de estancamiento. Este término hace referencia a la región del levantamiento donde se puede fallar durante el entrenamiento o la competición. Se define como la región entre el primer pico máximo de velocidad y el pico mínimo de velocidad durante la fase ascendente de

un levantamiento. La causa del fenómeno parece ser una desventaja mecánica del grupo muscular más débil involucrado. Esta región es altamente individual ya que depende de la cantidad de masa muscular del participante y cómo está distribuida, el grado de experiencia del individuo en el patrón motor que se testea y la forma articular y longitud ósea del participante. Se han adoptado diferentes estrategias para combatir la región de estancamiento, que podemos clasificar en estrategias a largo plazo (como el entrenamiento específico) o a corto plazo (donde la PAPE podría ser útil).

Por tanto, los propósitos principales de esta tesis fueron: (i) observar si una estrategia para mejorar el rendimiento de forma aguda (es decir, PAPE) es efectiva sobre la cinemática y las características de la región de estancamiento, (ii) comparar diferentes protocolos de PAPE basados en diferentes regímenes de contracción y (iii) estudiar si un protocolo de PAPE puede mejorar el volumen de entrenamiento de fuerza.

La tesis comienza con una revisión sistemática de la literatura científica, cuyo objetivo es determinar la combinación ideal para un protocolo de Potenciación Post-Activación cara a mejorar el rendimiento. Realizamos una búsqueda bibliográfica en octubre de 2020 (PubMed y Scopus) de artículos de investigación originales. Después de analizar 202 resultados, solo se incluyeron los estudios que cumplieron con los siguientes criterios de inclusión: a) la edad de los sujetos era entre 18 y 30 años; b) los estudios analizaron levantadores experimentados; c) la Potenciación Post-Activación se estudió en deportes con altos requisitos de la tasa de desarrollo de la fuerza; d) el protocolo de potenciación se realizó con ejercicios con barra; e) la evaluación previa y posterior se realizó con un ejercicio de fuerza, salto vertical o similar (es decir, un *squat jump*, salto en contramovimiento o *drop jump*). Solo se seleccionaron estudios revisados por pares escritos en inglés. Diecisiete estudios cumplieron con los criterios de inclusión, diez tenían un nivel de evidencia 1b (ensayos controlados aleatorios de buena calidad) y los 7 restantes tenían un nivel de evidencia 2b según la escala de nivel de evidencia de Oxford. De acuerdo con los resultados, incluso si se pueden usar diferentes protocolos para lograr la PAP, parece que las intensidades más altas inducen una mayor mejora del rendimiento. Más precisamente, parecía que (i) los levantadores experimentados se benefician más que sus compañeros sin experiencia, (ii) las intensidades altas brindan mejores resultados, y (iii) los intervalos de descanso de 7-8 minutos parecen apropiados.

Basándonos en esos resultados, intentamos comparar un protocolo de PAPE basado en un régimen de contracción diferente con un protocolo de PAPE tradicional de alta intensidad. El estudio tuvo como objetivo analizar el papel de un protocolo de PAPE de contracción isométrica máxima en el rendimiento y sus efectos en la cinemática de la región de estancamiento en comparación con un protocolo de PAPE tradicional. Para ello, se reclutaron veintiuna personas (edad 26.4 ± 5.4 años) que realizaron dos sesiones experimentales: una consistía en realizar una serie de una única repetición en press de banca plano con el 93% del 1RM (considerado un protocolo tradicional para inducir PAPE) y otra sesión que consistía en realizar 15 contracciones isométricas voluntarias máximas en la región de estancamiento de 1 segundo de duración, con 1 segundo de descanso entre contracciones. Los datos analizados incluían la velocidad de propulsión media de la región pre-estancamiento, el primer pico máximo de velocidad y el primer pico mínimo de velocidad. Solo el protocolo isométrico de PAPE mejoró el rendimiento en la región de pre-estancamiento (velocidad media desde el inicio del levantamiento hasta el primer pico máximo de velocidad) ($p < 0.001$; ES = 0.67, efecto moderado), velocidad en el primer pico máximo ($p = 0.005$; ES = 0.71, efecto moderado) y en el primer pico mínimo ($p = 0.025$; ES = 0.38, efecto pequeño). Los hallazgos de este estudio sugieren que un protocolo de PAPE isométrico de alta intensidad mejora la cinemática de la región de estancamiento y de la región previa al estancamiento, lo que ayuda al levantador a superar el levantamiento. Esta mejora es especialmente evidente en el primer periodo de la subida, previo a la región de estancamiento, mejorando el primer pico máximo de velocidad después del protocolo isométrico. Esto tiene como resultado la obtención de mayor impulso, facilitando así el paso por la región de estancamiento y cambiando el perfil velocidad-tiempo.

Como los protocolos de PAPE suelen usarse en tareas con carga submáxima o tareas explosivas, tratamos de probar si un protocolo de PAPE es útil cuando se trata de mejorar el volumen de entrenamiento. Este último estudio tuvo como objetivo analizar la influencia de un protocolo de PAPE en el rendimiento de press de banca en una serie de entrenamiento al fallo muscular en individuos entrenados en comparación con un grupo control sin protocolo de PAPE. Reclutamos catorce participantes con al menos 2 años de experiencia en entrenamiento de fuerza (edad 24.57 ± 2.7 años; masa corporal 77.47 ± 12.2 kg; altura 174.21 ± 7.4 cm 1 repetición máxima en press de banca con agarre medio (1RM): 101.6 ± 25.8 kg), de los cuales 14 completaron el protocolo de control y 12 el experimental. En el grupo que realizó un protocolo de PAPE, los participantes realizaron más repeticiones que en la condición control ($p=0.008$; ES=0.5, efecto pequeño), su última repetición fue más lenta ($p=0.02$; ES=0.52, efecto pequeño) y tuvieron una mayor pérdida de velocidad ($p=0.004$; ES=0.75, efecto moderado). Los resultados de este estudio sugieren que realizar un protocolo de PAPE tradicional antes de una serie al fallo podría hacer que el atleta sea más resistente a la fatiga en tareas de larga duración, lo que podría resultar en una potencial forma de mejorar el volumen de entrenamiento. La cantidad de trabajo realizado por sesión, entendido como número de series o como tonelaje (series x repeticiones x kilogramos) está relacionado con la cantidad de masa muscular ganada. Por lo tanto, si la PAPE mejora el número de repeticiones hasta el fallo concéntrico, el tonelaje por sesión aumentaría, y lo mismo podría ocurrir con la hipertrofia muscular. Puede asumirse que esa hipotética mejora en la hipertrofia muscular se debe a una tensión mecánica mayor en la última repetición y al mayor número de repeticiones realizadas. Sin embargo, el estudio se realizó con una sola serie, pero no se probó el efecto de esta serie y su fatiga en posteriores series.

La principal conclusión de esta tesis fue que existe un distanciamiento entre la ciencia y la práctica, ya que los protocolos que se utilizan habitualmente no son efectivos en los contextos comúnmente usados (es decir, sesiones de fuerza máxima o competiciones de *powerlifting*). Los protocolos alternativos (como los protocolos isométricos) son más adecuados para esas situaciones, ya que las ligeras mejoras en la cinemática de la región de estancamiento pueden ser cruciales cuando se tiene éxito en un intento de 1RM. En cuanto a los protocolos de PAPE tradicionales de alta intensidad, deben usarse principalmente en tareas de carga submáxima, donde combinados con un intervalo de descanso adecuado pueden brindar claros beneficios.

Palabras clave: Potenciación Post-Activación; mejora del rendimiento post-activación; Región de estancamiento; powerlifting; AMRAP; fallo muscular; entrenamiento de fuerza; volumen de entrenamiento; fuerza isométrica

LIST OF SYMBOLS AND ABBREVIATIONS

PAPE: Post-Activation Performance Enhancement

ATP: Adenosine Triphosphate

PAP: Post-Activation Potentiation

CA: Conditioning Activity

1RM: 1 Repetition Maximum

ROM: Range of Motion

min: minutes

Ca^{2+}: Calcium ions

MLCK: Myosin Light Chain Kinase

S1: Subfragment 1

S2: Subfragment 2

mM: millimolar

KCl: Potassium chloride

CAD: Catalytic Domain

CD: Converter Domain

LD: Lever Domain

nm: nanometre

A1: Low energy state

A2: High energy state

ΔG: Basic free energy change

ΔH: Change in enthalpy

$T\Delta S$: T stands for temperature; ΔS stands for entropy change

MVC: Maximal Voluntary Contraction

SERCA: Sarco/Endoplasmic Reticulum Ca^{2+}-ATPase

π: Pi

ΔP: Pressure change

r^4: Radius to the fourth power

η: Viscosity

l: length

F: Blood flow

$F_{thickness}$: Compressive force upon the muscle

F_{radial}: Force in the radial direction caused by $F_{thickness}$

CMJ: Counter Movement jump

CPX: Complex

CPX – CNT: Contrast complex

CPX – DT: Descending complex

CPX – AT: Ascending complex

CPX – FCNT: French complex

RFD: Rate of Force Development

Vs.: Versus

PPA: Potenciación-Post Activación

PEDro: Physiotherapy Evidence Database scale

RCT: Randomised Controlled Trials

BPM: Beats Per Minute

RPE: Rate of Perceived Exertion

V_{max}: Maximum velocity

V_{min}: Minimum velocity

$V_{max\ peak}$: Maximum peak velocity

$V_{min\ peak}$: Minimum peak velocity

ISO: Isometric conditioning protocol

TRAD: Traditional conditioning protocol

MVIC: Maximal Voluntary Isometric Contraction

ANOVA: Analysis of Variance

ES: Effect Size

CI: Confidence Interval

σ^2: variance of the response variable

1-β: statistical power

α: alpha level

CON: Control condition

SD: Standard deviation

η^2: Eta-squared, used in statistics as an index of the proportion of variance

RPD: Rate of Power Development

p: Significance level. Statistical measure used to validate a hypothesis.

EMG: Electromyography

F: Force

m: Mass

a: acceleration

V_{max1}: First maximum peak in velocity

$m \cdot s^{-1}$: meter per second

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INTRODUCTION

E´er to a truth that hath a falsehood´s face

Ought one to close his lips as best as he can,

For, though one faultless be, it brings him shame

Dante Alighieri – Inferno XVI (124-126)

1. INTRODUCTION

1.1 General Introduction to the Topic

This thesis studies the effect of a novel and different protocol of post-activation performance enhancement (PAPE) in the performance and kinematics of the sticking region of the bench press and the effects of the PAPE on training volume. The 3 published studies[1–3] start with a review of the scientific literature to establish what is recommended by experts and coaches in the field[1]. The purpose for that previous literature search was based on the broad spectrum of available protocols and rest time recommendations.

The second study[2] then examined the effectiveness of an isometric PAPE protocol in performance based on previous literature[4,5]. As new protocols with different contraction regimes have been proposed[6] and previous literature suggested the effectiveness of isometric contractions as potentiation stimuli [4,5], the intention of this study was to prove the efficacy of those isometric protocols in field conditions. Thus, a common exercise was tested, the barbell bench press[7], with an isometric contraction protocol, 15 maximal voluntary contractions of 1 second with 1 second rest interspersed. Shortly, we discovered that 15 maximal contractions interspersed with 1 second rest resulted in an effective potentiation stimulus.

Finally, the third study[3] analysed the effect of a traditional PAPE protocol on a task to failure in the bench press, as a possible mechanism to enhance training volume and maximise muscle mass gains. In this within-subject study, participants performed the control and experimental conditions in a randomised order. In both conditions participants performed a task to volitional failure with the 80% of their 1RM in the bench press, but in the experimental condition they performed a traditional PAPE protocol prior to the task to failure. Results indicate that PAPE could be a useful tool to improve performance in submaximal intensity tasks, improving performed volume. But, before starting into much of what is described above, some important and recurrent terms are defined in the following section.

1.2 Background and Definitions

Resistance training has gained popularity over the years as its benefits [8–10] and muscle tissue´s benefits[11–13] for health have been unmasked. Also, the popularity of strength competitions (such as strongman, weightlifting, and powerlifting competitions) and physique shows (such as bodybuilding) have increased exponentially. In an eagerness for rapid muscle mass gain, some basic concepts of resistance training are devaluated, such as the importance of a proper warm-up. Warming up prepares the whole system for what is coming during the training session raising body temperature (increasing Adenosine Triphosphate -ATP- turnover, muscle fibre functionality, cross-bridge cycling, and conduction velocity) and thus, being able to achieve the best performance possible[14]. There are plenty of protocols available, such as passive body temperature raises, plyometrics, low volume, and heavy resistance training bouts, mobility drills, post-activation potentiation and so on[14]. Briefly said, warming up prepares the body for the stress bout that training supposes.

Once the warm-up is performed, we are ready to train. It is known that in order to adapt, we must put our bodies under a controlled amount of stress[15–17], which has been postulated both in the general adaptation syndrome [15] and in the subsequent fitness-fatigue model[17]. To standardise training bouts and fatigue management, and consequently the applied stress, several quantification methods have been proposed. One of those methods is the measurement of the mean propulsive velocity (in $m \cdot s^{-1}$) and the velocity loss (expressed in $m \cdot s^{-1}$ or by a percentage) of the lift[18]. When a set is performed really close to muscle failure, the velocity-time relationship of the lift changes, and a zone known as sticking region appears[19,20]. It is well known that training to failure leads to greater stress than not training to failure[21]. Nevertheless, whenever the objective is to improve performance *per se* or to improve performance to gain muscle mass, training near to muscle failure is needed to optimise gains[22,23] , but should be wisely periodised[21,24]. The closer to failure, the higher the produced fatigue [25,26]. As higher volumes seem to bring more gains[27,28] , it seems intelligent approaching failure but trying not to detriment the total amount of volume that we are capable to tolerate. In this way, resistance training should be executed always under the supervision of a professional, or at least, following some good, evidence-based, and structured guidelines.

As evidence seems solid against training systematically to failure, whether you are an experimented or novice lifter, it seems reasonable to optimise the warming up strategy to avoid failure during lifting. As mentioned earlier, several strategies are available, but this thesis focuses on the effects of the post-activation performance enhancement on the sticking region kinematics.

1.2.1. Post-Activation Potentiation or Post-Activation Performance Enhancement?

1.2.1.1 Brief definition

Both Post-Activation Potentiation (PAP) and PAPE refer to an improved contractile capacity of a muscle after an intense bout of exercise, known as conditioning activity (CA). This is, after an intense bout of exercise the muscle tissue has an improved capacity to exert force voluntarily for a given stimulus or against a given resistance. The main difference between PAP and PAPE is that to confirm the presence of the first one, electric stimulation is used, while the term PAPE is used when confirmation via electric stimulation is not carried out[29] .

The conditioning activity must accomplish some requirements to produce an improvement in performance:

a) There must be a biomechanical similarity between conditioning activity and the tested movement[1]
b) A minimum intensity is needed, achieved using either high-load and low-velocity exercises or light-load and high-velocity exercises[30]. When high-load and low-velocity protocols are used, excessive proximity to muscle failure must be avoided, as high fatigue is produced[21,24].
c) Recovery between conditioning activity and the tested movement is of utmost importance. In this way, stronger individuals can benefit from shorter rest intervals (5-7 mins) than non-trained or weaker individuals (>8 mins)[31]. In addition, it seems that self-selected rest intervals adjust well to each one´s needs[32].

The mechanisms behind PAPE are not fully elucidated. In the beginning, the phosphorylation of the regulatory light chain of myosin was proposed as the underlying mechanism (as in the case of PAP), but discrepancies in the occurring time were found. This led to the creation of new terms and the proposal of new mechanisms.

1.2.1.2. History of Post-Activation Potentiation

First investigations talking about a topic related to post-activation potentiation (PAP) go back to the early XX century, where Lee[33] studied in more detail what described Bowditch in 1867. In his study, Lee described what the *treppe* was, or, in English, the staircase potentiation. This staircase potentiation is based on the achievement of better muscle contraction after the application of repeated low-frequency stimulations as conditioning activity or stimulus. Later in that century, in 1937, the term *post-tetanic potentiation*[34] was born, which refers to an observed augmentation of the tension produced by a fibre after tetanic contraction. Finally, in 1976 Burke et al. (1976)[35] introduced the term *post-activation potentiation* (PAP), where they used frequencies and number of pulses more similar to what our body can achieve physiologically. This established a well-marked difference between post-tetanic potentiation and PAP. Nowadays, is commonly accepted that PAP is confirmed when an amplitude in twitch contraction is measured (a twitch is the contractile response to a single electrical stimulus applied directly to the muscle or the motor nerve). Thus, PAP needs of electrically evoked verification, but this seldom happens. This is one of the reasons why the term Post-Activation Performance Enhancement (PAPE) was proposed, which refers to a performance enhancement produced by a voluntary action (like PAP), but with no twitch verification[29] . This problematic will be further discussed in "*the confusing taxonomy problem*" section.

1.2.1.3 The diversity of PAPE protocols

Numerous PAPE protocols have seen the light over the last years with the intention of improving acute performance in resistance training. The most common protocol that can be seen in almost every gym is a high-intensity and low-velocity protocol, where a near maximal lift is performed. For this type of protocols, a heavy set of one repetition is performed before the effective work or the training session itself, looking for improved performance in that exercise. This "heavy set" is usually performed between 93-100% of the one repetition maximum (1RM), and frequently, this repetition reaches failure and relies on the help that a spotter (the person taking care of the participant not getting hurt during the training session) gives to that trainee. This usual protocol of PAPE reminds us the "forced repetitions" advanced training method for hypertrophy[36], which relies on reaching failure and getting help to perform some more repetitions. While the forced repetitions method could be interesting to achieve muscle hypertrophy when prescribed wisely, they are not to achieve PAPE, as acute fatigue is more than needed and could underpin the benefits. Anyway, the use of this protocol is derived from a misinterpretation of scientific work behind.

When applied correctly, this high-intensity and low-velocity protocol should be relatively near to, but not reach failure[1]. This is based on the fitness-fatigue model[17], which usually is applied in the long term, but nothing seems to suggest that it cannot be used for short-term or acute adaptations as PAPE. According to this model, the higher the applied stimulus, the higher the main fitness effect, but also the fatigue effect (and thus, the needed rest interval is greater). As a matter of fact, the 8th figure illustrated in the classic study by Tillin and Bishop (2009)[37] reminds that depicting the fitness-fatigue model in figure 1 by Chiu and Barnes (2003)[17]. This suggests that there are different time-potentiation profiles depending on chosen intensity and volume. Research supports this idea. Gilbert and Lees[38] found different potentiation-time profiles for their high-intensity and low-intensity protocols, where the 1RM group showed the greatest performance 20 min after the conditioning activity, while the lighter load protocol group showed the best performance 2 min after. Other studies using fixed rest intervals show fewer performance improvements when the load is heavy[39]. In the research by Kilduff et al. (2008)[40], long rest intervals were needed (~8min) for a high intensity protocol and Do Carmo et al. (2018)[32] stated that self-selected rest intervals were also appropriate.

Following with intensity, during these last years, supramaximal protocols have been proposed[6,41], which have proven to be effective when improving power and velocity output in the bench press of strength-trained athletes. This is a promising new protocol to induce PAPE, but it has some limitations that we should consider:

1. Even if the bench press is a good exercise for this type of protocols, it should be extrapolated cautiously to other competitive movements such as squat or deadlift, as their range of motion (ROM) is usually greater.
2. Even if it is highly individual, it is more common that lifters find deadlift and squat more difficult movements than bench press. This augmented complexity in its motor pattern can induce greater mental fatigue[42,43], which would add to the

elevated fatigue that produces a higher load in the barbell (the eccentric supramaximal protocol).

3. In addition to the previous point, an augmented demand for attention due to the complexity of the motor pattern, could lead to greater injury risk. The more complex the task, the greater the challenge to learn it or to maintain it under challenging situations (as a supramaximal protocol), making it easier to commit a mistake and get injured.

These stated points do not have the intention to dismiss the promising results of that new protocol. These points aim to highlight the importance of context, as the supramaximal protocol seems intriguing but more suitable for advanced athletes and safer and easier movements, like the bench press.

On the other hand, we can find light/medium-load and high-velocity protocols. For example, protocols with the optimal power load have been carried out[38,44] and seem to provide different time-potentiation profiles due to the reduced accumulation of fatigue. Usually, when performing a power load protocol, several repetitions are left in reserve[45], performing sets further from failure and producing less fatigue[21]. Also, we can find compound methods, like the French Contrast[30,46] in which plyometric contractions are combined with heavy resistance lifts. It is as follows:

1. A heavy compound exercise (high-intensity and low-velocity)
2. A stretch-shortening cycle plyometric exercise
3. Light or moderate loaded compound exercise to maximise power production (i.e., optimal power load protocol)

4. An assisted plyometric exercise

Finally, it is worth mentioning that in some powerlifting meets and, in some gyms, a type of “psychological PAPE” is common. Coaches prescribe isometric holds with supramaximal weight before the effective work. An example could be unracking the 115% 1RM and holding it for 10 seconds, without performing the squat. After that, the athlete rests for 2-4 min and starts with the effective work or the competition. The objective is to have the sensation that the weight we are using in the competition weighs less because we have unracked a heavier weight before. The success of this protocol is based on the maximal adaptability theory[47], which states that hyperstress could lead to bad performance, and so could hypostress. If the athlete unracks the barbell and notices too much weight on his or her back and becomes fearful, the athlete is adding him or herself more psychological stress to the situation, which could deviate the attention from more important technical aspects and lead to a technical breakdown (which, ultimately, leads to a failed lifting attempt). On the other hand, if the athlete is over-confident after that psychological PAPE protocol, he or she could not pay enough attention to technical aspects, and lead to a technical breakdown equally. We know from current literature that when a movement or task requires only force, attention is not that important, but when a task is attention demanding, focusing on what we are doing is crucial for optimal performance and force output[48].

1.2.1.4 PAPE and bodybuilding, is it useful?

The primary objective when using PAPE should be improving acute performance, whether it is in field, track, team, combat, or strength sports. Additionally, PAPE has started to be studied as an acute mechanism to improve the total performed volume during a training bout, with the intention of improving muscle mass gains per session[49,50].

It is already known that body composition improves when fat tissue is minimised[51] and hypertrophy of muscle cells is achieved[52,53]. To provide a good stimulus for the muscle, elevated mechanical tension must be achieved[22], and repetitions in reserve have proven to be a reliable tool to quantify it[28,54]. This mechanical tension will stimulate the muscle cells to adapt[55–57], and this will happen independently of the performance understood as absolute load (kg or lb in the barbell, dumbbell, or machine), but due to the fatigue and proximity to failure[26].

Nevertheless, it seems that there is a relationship between the amount of work performed and the gains obtained, but only to a point, after which it starts being detrimental to keep applying stimulus[27]. PAPE has demonstrated to improve performance to volitional failure in sets of several repetitions[49], which is in line with our study[3].

Anyways, there is a misunderstanding in the rationale to use PAPE for bodybuilding. The reason why people use PAPE protocols to optimise body composition is that they think moving more weight produces greater hypertrophy. This spurious reasoning is based on the association between people with elevated muscle mass and their performance in those exercises known as "basics" (i.e., squat, deadlift, and bench press). Nevertheless, the correlation works on the other way: they have not that elevated muscle mass because they have great squats, but they have great squats due to their elevated muscle mass[58]. Whether those basic exercises are mandatory or not to optimise muscle mass is beyond the scope of this thesis. Consequently, the intention of improving performance of the nervous system to improve muscle mass gain is nonsense, as mechanical tension is the primary muscle hypertrophy driver[26,57] (even if neural stimulation is the previous step to produce that mechanical tension[56]).

Anyway, albeit promising, there is a lack of empirical evidence supporting the use of PAPE for bodybuilding, and theoretical evidence is rather scarce.

1.2.1.5 The mechanisms behind PAP and PAPE, could they be the same phenomenon?

Until this point two phenomena have been mentioned: PAP and PAPE, whose differences are: (i) the need for electrically induced confirmation in the case of PAP, and (ii) the potentiation-time profile. This last point refers to the time from the conditioning activity to the tested movement. In this sense, PAP has a shorter lifespan (~4-5 min), while PAPE could last until 20 min[38]. Are they produced by different physiological mechanisms?

The mechanism behind PAP seems to be myosin regulatory light chain phosphorylation[29,59]. With maximal or almost-maximal voluntary contractions as conditioning activity, influx of sarcoplasmic calcium (Ca^{2+}) into myoplasm activates myosin light chain kinase (MLCK)[29,60]. As with any other kinase-phosphatase system, this mechanism relies on the addition or removal of phosphate groups from one molecule to another[61,62]. Once MLCK has been activated, it phosphorylates one specific region of the myosin subfragment 1 (S1) head, very close to its joint with subfragment 2 (S2) portion[59,60,63]. This phosphorylation augments the probability of a cross bridge to occur improving myosin head´s mobility, allowing potentiated fibres to improve their rate of force development[64]. Yet, this improvement in contraction lasts ~4-5 min, while protocols used in field conditions provide larger rest intervals[1,6,65].

Could the nervous system be responsible for this time discrepancy between PAP and PAPE? Does the nervous system play a role in PAPE? Does it matter when improving performance? The study by Krutki et al. (2017)[66] shows an improved excitability of motoneurons in rats, where both fast and slow motoneurons became more sensitive to the applied stimulation. In addition, it seems that with strength training, changes in the corticospinal tract can happen, altering the excitability of corticospinal-motoneuronal projection. The study by Nuzzo et al. (2016)[67] found improvements in performance at the same time that they discovered neural facilitation of cervicomedullary motor-evoked potentials (i.e., producing corticospinal neural activity below cortical level). This neural facilitation, also known as paired-pulse facilitation, is given when two post-synaptic potentials are released very close in time. The closer in time, the greater the facilitation[68]. This facilitation could serve to augment drastically the applied force in the initiation of the movement[69]. In the study by Nuzzo et al. (2016)[67] is believed that neural facilitation was a product of improved efficacy of corticospinal-motoneuronal synapses. This shows the possible involvement of the neural system.

But before digging in, it is paramount to consider some points when studying PAP or PAPE, as the achieved effects can be attributable to them or to another side effects such as temperature raises, motor pattern learning, or caffeine intake. Following this line of thought, MacIntosh et al. (2012)[29] facilitated some points to consider when designing research:

I. Two or more conditions must be compared

II. Subjects must have marked experience in the performed task. If they do not have experience, familiarisation is crucial, as the learning effect could lead to misinterpretations of results.

III. Conditioning protocols should be applied in random order

IV. If possible, a double-blind approach should be considered. As the researcher cannot be blinded, it is important that subjects do not know what protocol they are going to run, and is of uttermost importance that they do not know what researchers expect of the protocol, as results could be biased

Is worth mentioning that MacIntosh et al. (2012)[29] highlight the importance of monitoring body temperature whenever possible to be able to distinguish effects caused by PAP/PAPE or by the temperature raise itself[14,70].

Blazevich and Babault[59] mention some possible mechanisms to explain PAPE´s time course, such as increased water flow into the muscle cell, which could lead to improved Ca^{2+} sensitivity, which ultimately leads to an augment of rate of force development. As a matter of fact, Sugi et al. (2013)[71] stated that in conditions of low ionic strength (low concentration of ions in a solution), muscle fibres could exert higher forces than compared to those conditions of higher ionic strength (50mM and 170mM KCl respectively), even if maximum unloaded shortening velocity remained unchanged. They attributed the improvement of force to an amplification of the force exerted by every myosin head (increasing twofold) rather than to the quantity of formed crossed bridges. In a later study by the same group[72] an electron microscope combined with an environmental gas chamber was used to assess more accurately myosin´s power stroke mobility. Shortly, the myosin head can be divided into the following parts: (i) The catalytic domain (CAD) that has a proximal (respect to the myosin backbone) and a distal part, (ii) the converter domain (CD) and (iii) the lever domain (LD), which is bound to the Subfragment 2 (S2) of the myosin (Figure 1).

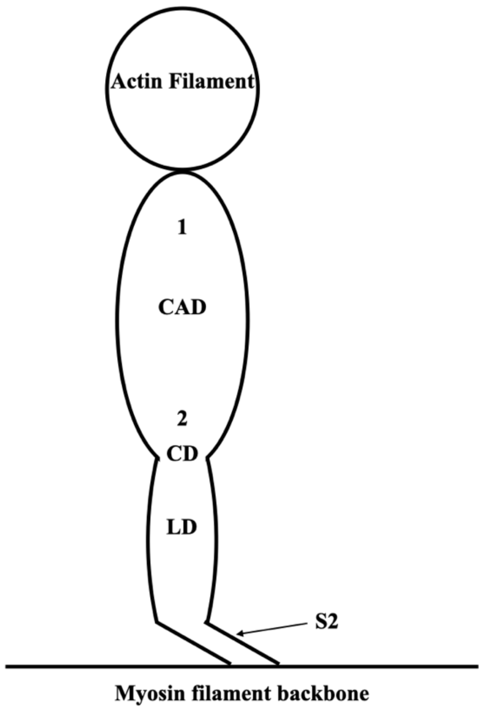


Figure 1. Representation of the myosin head and its parts. CAD: Catalytic domain; 1: Binding site for antibody 1, CAD distal part respect to the myosin backbone; 2: Binding site for antibody 2, CAD proximal part respect to the myosin backbone; CD: Converter domain; LD: Lever domain; S2: myosin subfragment 2. Adapted from Sugi et al. (2015)[72]

In this study[72], researchers showed that under normal conditions, the distal portion of CAD performed a power stroke of 3.3 ± 0.2 nm (n = 732) and the proximal region of CAD 2.5 ± 0.1 nm (n = 613), while in low ionic strength condition, the distal portion of CAD performed a power stroke of 4.4 ± 0.1 nm (n = 361) and the proximal portion 4.3 ± 0.2 nm (n = 305). This increment in the performed power stroke is in line with the hypothesis that in low ionic strength conditions the improved force is due to the augmentation of force per myosin head rather than to the number of cross-bridges formed. Nevertheless, the accretion of water content inside muscle cells (also known as cell swelling) is produced after an intense bout of resistance training[23] or by augmented blood perfusion, so further research is needed to know if the minimal cell swelling that a warm-up produces could be effective to improve the force exerted by each myosin head.

Another promising mechanism to explain the elusive mechanism behind PAPE is muscle temperature. Decostre et al. (2005)[73] studied the effect of different temperatures over the working stroke of actin-myosin. In this study, the working stroke was divided into four phases:

I. Phase 1 is a change in length due to the elastic components of the sarcomere
II. Phase 2 is the shortening directly produced by the working stroke
III. Phase 3 is the reduction of shortening velocity due to detachment and reattachment of the myosin head along the actin filament
IV. Phase 4 Final shortening at constant velocity due to steady-state detachment/attachment of myosin heads

In their study, Decostre et al. (2005)[73] found that with increasing temperature phases 2 and 4 were faster, while phase 3 was shorter. Additionally, they found that both passive and active elements of the sarcomere were strained in proportion to force, pointing to a rise in force per myosin head as the reason why the increase in temperature produces more force. This augmented force per myosin head could be due to a higher quantity of myosin heads in a high energy state. Authors propose that the increase in temperature provokes a lowering of basic free energy, facilitating the transition of myosin heads from a low energy state (A_1) to a high energy state (A_2). The lowering in basic free energy makes the reaction happen easier or even spontaneously ($\Delta G = \Delta H - T\Delta S$; this results in $\Delta G > 0$), making it easier for myosin heads to achieve the high energy state. But the principal limitation of this study is that the temperatures they use are very low (between 2ºC – 17ºC), which makes the results difficult to extrapolate to physiological conditions, even if it shows that temperature could play an important role.

In addition, the role of temperature in muscle contraction was recently addressed by Rodrigues et al. (2022)[74] in their review. In this study are mentioned two further studies, one by Racinais et al. (2017)[75] where participants improved their maximal voluntary contraction (MVC) and another study by Goto et al. (2011)[76] where participants improved their muscle mass. I would like to highlight some points here. First, in Racinais et al. (2017)[75] there is no description of participants´ experience level in strength training, so possibly they could be novices. In Goto et al. (2011)[76] participants do not practice serious or competitive level sport, only recreationally. Also, in this last study, muscle mass is augmented, but muscle mass augmentation and improvement of functional hypertrophy are not the same, as the main objective of any resistance training plan is to seek an augmentation of contractile protein quantity[52]. Finally, is worth mentioning that both studies talk about passive heating protocols, which helps us understand the potential interests of studying temperature effect on performance, but results should be taken carefully, as passive heating protocols are long and not applicable in field conditions (1h / day over 11 days[75] and 8h /day, 4 days /week over 10 weeks[76]).

Leaving aside long-term temperature raise´s potential benefits, Rodrigues et al. (2022)[74] focus the rest of the review on the acute effects of temperature raises. They defend that temperature raises improves half-relaxation time of the contractile apparatus, which would be caused by the improved kinematics of Ca^{2+}, as suggested by the improved activity in the Sarco/Endoplasmic reticulum Ca^{2+}-ATPase (SERCA), that has as the main function to transport Ca^{2+} from cytosol back to the sarcoplasmic reticulum[61].

Water and temperature seem two promising mechanisms for PAPE, but could they be related somehow? Could they be two sides of the same coin?

The review by Rodrigues et al. (2022)[74] follows exposing that temperature raises can cause blood perfusion by an increased liberation of adenosine triphosphate (ATP), which acts as a vasodilator. When vasodilation occurs, blood flow increases following Poiseuille´s law[61], which states that:

$$F = \frac{\pi \cdot \Delta P \cdot r^4}{8 \cdot \eta \cdot l}$$

Here we can see that if pressure difference (ΔP), viscosity (η), and length (l) are kept constant, blood flow (F) will increase proportionally to the fourth power of the radius of the blood vessel (r^4). This augmented flow is due to the laminar flow of the blood when the radius increases. In small vessels, all the blood inside causes friction against the vessel´s walls, while increasing the blood vessel´s radius increases the amount of blood that can get inside. If more blood gets inside the vessel, only the outermost layer of blood will cause friction against the blood vessel´s wall and the centermost layer will circulate faster (which is known as laminar flow parabolic velocity profile)[61,77,78].

This augmented blood flow due to vasodilation increases intramuscular water content, which leads us again to Sugi et al. (2013; 2015)[71,72] , but still we do not know why it happens. The answer could be in the studies by Eng et al. (2018)[79] and Eng & Roberts (2018)[80].

In their studies, Eng et al. (2018)[79] and Eng & Roberts (2018)[80] state that due to the isovolumetric property of the muscle fibre, when it contracts, it can be deformed in any direction orthogonal to the line of action. When McKibben actuators were disposed close to each other to mimic real muscle fibre conditions during muscle contractions, they saw that each actuator limited the upwards and downwards expansion of the adjacent actuators, producing a radial expansion to the sides, and even rotations, if needed. One of the most important things highlighted in this model is that those forces that are not aligned with fibres´ line of action (those off-axis forces), load intramuscular connective tissue and fluid. These off-axis forces are caused by compression of intramuscular fluid, requiring fibres to expand radially as they shorten. The second cause of the off-axis forces are the thickness forces generated in pennate muscles, the component of the force that compresses muscle in the thickness direction. Thus, there are two forces deforming muscle fibres: (i) the thickness force that crushes muscle "from upside down" and (ii) the radial force that expands the fibre. Authors hypothesise that to counteract the thickness force, intramuscular fluid expands causing the radial expansion. This radial expansion loads muscular elastic elements such as endomysium, perimysium, and epimysium (Figure 2).

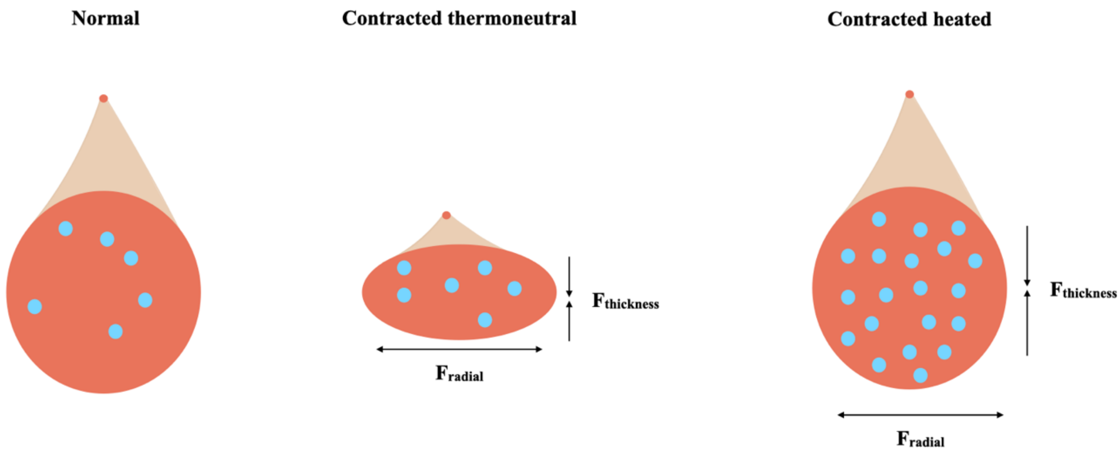


Figure 2. Link among temperature, water content and force transmission. Filled blue circles represent water molecules; $F_{thickness}$: Force in the upside-down direction that crashes or compresses the muscle; F_{radial}: Radial expansion produced by fluid in response to $F_{thickness}$. Adapted from Rodrigues et al. (2022)[74]

In summary, intramuscular fluid redirects the thickness compressive force to radial stretching force, for which muscles are prepared due to their elastic components. Considering this, increments in intramuscular water may enhance muscle compressive force tolerance, acting like a spring, and improving force transmission[74], which could explain the link between water and muscle temperature in enhanced produced forces.

Even if this seems promising as an explanation of PAPE, what difference would be between a temperature raise caused by a classic warm-up and a temperature raise caused by PAPE? Could this temperature raise be significant? Weigert et al. (2018)[81] found small and non-significant temperature changes after 10 repetitions of biceps curl at 70% 1RM, suggesting that some PAP/PAPE protocols (the traditional heavy protocols consisting of 1 set of 1 repetition for example) are unlikely to rely on this mechanism. Boullosa et al (2018)[82] mention that a possible Ca^{2+} raise due to low-frequency twitches that could enhance performance in those protocols. This would produce an effect similar to MLCK activation, but without myosin phosphorylation.

In any case, existing PAP/PAPE protocols are diverse, some could rely in a mechanism and others in other mechanism. Could it be that PAPE is an extension of PAP over time? It is reasonable to think that myosin regulatory light chain phosphorylation occurs and that its effect is lengthened due to temperature raises, intracellular water content, improved Ca^{2+} sensitivity or another mechanism. As scientists, we tend to compartmentalise effects and its causes, but the human body is complex and nothing seems to suggest that PAP and PAPE happen independently one of each other[59,83]. This is, PAP occurs before PAPE because of the rapid action of MLCK, and PAPE occurs after for some mechanism not fully elucidated yet. But, even if PAPE has another mechanism behind, this does not mean that PAP could not contribute to PAPE´s effects. PAPE could perfectly be an extension of PAP over time by another synergistic mechanism.

1.2.1.6 The confusing taxonomy problem

Considering all that has been said in the previous section and remembering that PAP lasts ~4-5 min, why are so many studies talking about PAP and reporting performance improvements 8,10 or even 20 min after conditioning activity? There are more terms than PAP, and the unification of those terms seems harder than the elucidation of the mechanism behind PAPE.

Originally, PAP and PAPE were created with the intention of simplifying things to researchers: PAP was used to talk about potentiation verified with electric twitch, and PAPE when that verification was not carried out[84] even if in both cases the conditioning activity relies on a voluntary contraction.

However, a variety of new terms have been proposed in addition to those two original terms. One of the attempts to establish a more precise terminology was carried out by Boullosa et al. (2020)[85]. They defend that a more accurate terminology is needed to include some influencing factors like training experience[1], sex differences[86] and training background[87] . Following this line of reasoning, they propose the following scheme to name any potentiation protocol:

Post-(conditioning activity) (verification test) Potentiation in (Population)

Some examples of that scheme are provided in their paper:

- Post-high intensity long intervals, sprint potentiation in well-trained runners
- Post-eccentric flywheel squat swim start potentiation in varsity trained male swimmers

This is a really complete proposal, where all details are specified in the name of the potentiation protocol, but it does not seem really applicable in real life where more straight forward names are easier to remember. Based on the extreme complexity of this proposal, Smith and MacIntosh (2021)[83] replied, defending their old and simpler two term taxonomy (PAP & PAPE, irrespective of protocols, sex, or population).

Recently, Cormier et al. (2022)[30] tried a new taxonomy proposal. In this case, researchers summarise existing protocols to three possible types:

A. One or several sets of high-load exercise (back quat) before a low-load exercise (CMJ)

B. One or several sets of low-load and high-velocity exercise (CMJ) before a high-load exercise (squat)
C. Alternating high-load and low-load exercises in a set-by-set fashion

They propose a broader terminology than PAP and PAPE at the time that they notoriously simplify the terminology proposed by Boullosa et al. (2020)[85]. They start proposing "Complex" as an umbrella term which is going to be combined with four different sub-terms or implementations, namely:

I. Contrast: An exercise sequence alternating high-load and low-load exercises in a set-by-set fashion (e.g., Back Squat 85% 1RM – CMJ - Back Squat 85% 1RM – CMJ)
II. Ascending: Several sets of low-load exercise before a high-load one (e.g., CMJ – CMJ – Back Squat 85% 1RM – Back Squat 85% 1RM)
III. Descending: Several sets of high-load exercise before a low-load one (e.g., Back Squat 85% 1RM – Back Squat 85% 1RM – CMJ - CMJ)
IV. French Contrast: A heavy compound exercise – A plyometric exercise – Light or moderate compound exercise – Assisted plyometric exercise

Thus, combining the umbrella term (Complex – CPX) with its four sub-terms, depending on the characteristics of the protocol that is going to be used, the new terminology would be: (i) Contrast complex (CPX – CNT), (ii) Descending complex (CPX – DT), (iii) Ascending complex (CPX – AT), or (iv) French Contrast Complex (CPX – FCNT).

This last proposal seems the more suitable one, as it remains concise at the time it is specific. I would like to add that a new term should be created specifically for eccentric[6] and isometric protocols[2,88] , as interest in this type of contraction types as potentiation stimuli is gaining interest.

It is important to highlight that using this terminology does not imply that PAP and PAPE should be forgotten. Rather, we could interpret this new terminology as an expansion inside PAPE protocols, as protocols named by Cormier et al (2022)[30] are not usually confirmed through electrical twitches.

1.2.2 Sticking Region

1.2.2.1 Brief definition

This refers to the region of the lift where it can be failed during training or competition. It is defined as the region between the initial maximum peak in velocity and the first minimum peak in velocity during the ascending phase of a lift[20,89].

This sticking region is highly individual and seems to occur due to mechanical disadvantages. The individuality of the sticking region is produced by:

a) The quantity of muscle mass of the individual and how it is distributed. The importance of the individual´s muscle mass in strength output is elegantly highlighted in the study by Maden-Wilkinson et al. (2020)[58].
b) The expertise level of the individual. When an individual is new practicing the skill, the resultant force vector is not optimised, and the efficiency of the movement is low[90]. In addition to this, a well-trained individual can manipulate his or her technique to modify the resultant force vector to optimise efficiency.

c) Genetic differences in joint form and orientation and bone lengths[91,92]. Is known that genetics can influence the disposition of hip socket or humerus length for example. This will result in different mechanics of the body and the lift.

1.2.2.2 Sticking Point or Sticking Region?

The term "sticking point" is widely used in the resistance training population to describe the point of the ROM during the ascending phase where the lift is failed[20,89,93]. This term is of paramount importance for coaches looking for performance, as this is what we could call the weakest link of the lift. In any strength sport, the athlete is as strong as its weakest link, so improving this will improve performance. But before jumping right into training, what is this sticking point?

Like in any scientific field, terms are proposed to adjust as much as possible to reality, and consequently, these terms or even their definition are updated from time to time. The case of the sticking point is not different, as it started being defined as[94] :

the point during the ascending phase of the lift where the velocity of the barbell reaches a velocity of 0 $m{\cdot}s^{-1}$

The critics over this definition were based on the fact that there is no need to reach a velocity of 0 $m{\cdot}s^{-1}$ to appreciate the appearance of a sticking point. As a consequence, the definition was reformed to[95] :

the point in which the barbell reaches its minimum velocity during the propulsive phase of the lift

This definition corrects the principal flaw of the first one but was still incomplete. "Point" refers to a very well-defined position in space. In geometry, the "point" is defined as an exact location in space, what could be understood as an exact configuration of joint angles in which the sticking point occurs. The point in which that sticking point can occur is modifiable with technique, for example varying bench press width grip[89]. This leads to the conclusion that it cannot be an extremely exact point during the ascending phase, but a range. As the sticking point seems to occur almost always, but not at the exact joint angle configuration (but yes at similar joint angle configuration for a given technique), a third definition was proposed[96,97]:

The region of the ascending phase between the first maximum and first minimum peaks in velocity

Even if this last definition describes the phenomenon more accurately, new questions arose with it. This definition states that the sticking region is the zone or region between the maximum and minimum peaks in velocity, but what happens when one of those elements are not present? If we look for example to Stefi Cohen´s (an advanced female powerlifter) sumo deadlift, we can see that there is no minimum point of velocity. Her sticking region is the lift off itself, so the velocity will increase as she furthers from the ground. Considering the definition of the sticking region, she has not one, but she has failed more than one lift. How is it possible?

The answer to that question is that even if the definition of sticking region improves the previous definition adding the notion of a region rather than a point, it does not explain what the sticking region is but what happens. If we consider the sticking region as the region between the first maximum and minimum peaks in velocity[96,97], then we face a difficulty, as some exercises or techniques (as Stefi Cohen´s sumo deadlift) present a different velocity-time profile (Figure 3):

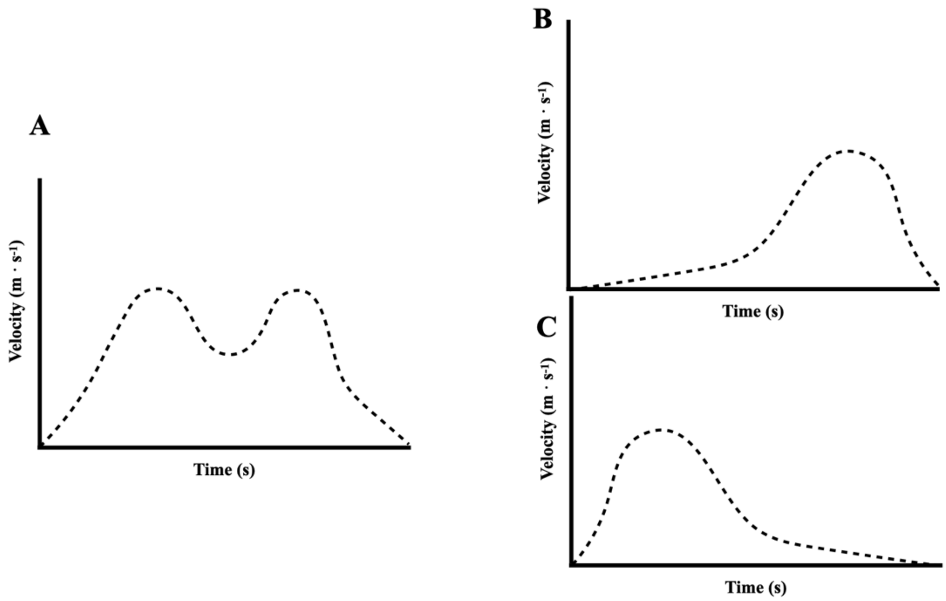


Figure 3. Different forms of a sticking region. A) Classic sticking region, with a 1st maximum and minimum peak in velocity; B) Sticking region during the first half of the lift, it only presents one maximum peak in velocity, not followed by a minimum. Very common in sumo deadlift powerlifting competitors; C) Sticking region during the second half of the movement, only presents a maximum peak in velocity, followed by a progressive velocity loss until the end of the movement. Common in some powerlifters with very close grip in the bench press. Adapted from Kompf & Arandjelović (2016)[20]

The National Strength and Conditioning Association defined the sticking region as[20]:

The weakest point in the range of motion of an exercise, probably due to a mechanical disadvantage

This seems a good definition, as it states what is the sticking region, and the key relies on mechanical advantage or disadvantage. The mechanical advantage of a musculoskeletal lever can be defined as the ratio between the internal moment arm and the external moment arm[98]. The internal moment arm is the moment arm of a given muscle over the analysed joint, while the external moment arm is the moment arm of the resistance (the dumbbell, barbell, cable or whatever) over the joint that is analysed. Shortly, this definition states that the weak muscle group involved in the performed movement is the cause of the velocity loss.

1.2.2.3 Can we avoid the sticking region?

If we, as coaches, could teach avoiding the sticking region, athletes would not fail lifts, obtaining better competition results. Knowing that the sticking region is produced by a mechanical disadvantage, the first idea to solve this problem could be changing the motor pattern (the technique of the athlete), shifting the demands to a stronger muscle group.

Even if this idea seems interesting, and even if changing technique, the demands could change slightly [89,93], that sticking region does not disappear. For example, in the study by Larsen et al. (2021)[89] different grip width changed bench press kinetics and kinematics, but the sticking region did not disappear, it only changed where it happened and what muscle was the most important.

The second idea is training that sticking region. This sticking region can be trained specifically, training the movement itself (training squats to improve squats for example) or eliminating all impulse prior to the sticking region (using pause squats or tempo 400 squats for example)[19,20]. Muscles present a force-length relationship[99], whenever the sticking region of an athlete happens when muscles are in the lengthened position (for example, when the barbell is paused over the chest during the bench press), training in higher ranges of motion can be beneficial. The higher ranges of motion, eccentric training or strength training at high muscle lengths can shift the force-length relationship[99–102], making the muscle stronger at higher lengths. On the other side, when the sticking region is near the finish of the movement (the lockout of elbows in the bench press for example), strategies as adding more load in that specific region using elastic bands or chains[103] , improving impulse prior to the sticking region[2,20], or even improving rate of force development (RFD) with high velocity training[104] could be reasonable strategies.

Aside these long-term strategies, where the focus is improving over a training period, is there any acute strategy to improve sticking region performance? In one of our studies[2] an isometric PAPE protocol improved sticking region kinematics in the first part of the range of motion of the medium grip bench press. This improvement is evident in the first period of the ascending phase, prior to the sticking region. The main finding is that the first maximum velocity peak is greater after isometric PAPE protocol, which provides the lifter with a greater impulse to overcome the sticking region. Also, the minimum velocity is higher after the isometric PAPE protocol. This changes in the velocity-time profile of the lift and the sticking region (i.e., less velocity loss from maximum to minimum velocity points) are due to the greater impulse that the lifter has achieved prior to the sticking region. Thus, acute improvements in the sticking region kinematics seem possible.

1.3 Theoretical Framework of the Thesis

1.3.1 Ideological Basis

As a new strength coach and Sport Science student, I wanted to learn as much as possible to apply all that knowledge into my work. When I started reading and learning on my own and realising how things work, how I could improve my training, I started noticing how people around me train in the gym. Of course, not everyone had a coach (either online or presential), but even some of those people under the supervision of an online coach, used to train following old guidelines or scientifically discredited methods, exercises or technical standards. Among those discredited terms and techniques, PAPE (what in gyms is still known as PAP) and Sticking Region (what, again, is still known as Sticking Point) were really popular. When I realised about this situation, interesting question came to me:

1. Why do so many coaches use the term PAP instead of PAPE
2. Why do so many powerlifting coaches say Sticking Point, and not Region?
3. Why do coaches use a PAP/PAPE strategy prior to a heavy set when most of studies are oriented to submaximal intensity work?
4. Why do coaches assume that better performance produced by PAP/PAPE equals more muscle mass gain?
5. Why don´t coaches use more than a traditional PAPE protocol?

This disconnection between scientific literature and coaches´ practice sparked the idea for this thesis. Why was this happening? Is science available and understandable for graduated students and coaches?

Strength training has gained notorious popularity. The quantity of publications, whether it is for health or performance, has raised notably (437 publications indexed in PubMed in 2000 *vs.* 5,886 publications indexed in PubMed in 2021). This is not unusual considering that in science, what is true today, can be refuted tomorrow by another study. But are those publications read by someone? When studying the Sport Science degree, we are taught how to look for information and how to filter that information, what in my own opinion, is the most important competence acquired during the 4-year journey. Those who really enjoy studying or who really appreciate the potential source of knowledge they are presented when learning these skills, are later known as scientists. Usually, whether they undergo a PhD or dedicate their life to divulgation in personal blogs or social networks, it does not matter, they are responsible for creating, interpretating and teaching what is new and what needs to be known. But what about trainers and coaches? Is science the privilege of a small population wearing white lab coats, the strange language of people that has never trained? Is one on one coaching reserved to those people that are only based on experience, to those foot soldiers?

Nowadays this division is happening and is something we should think about. If scientists are making contributions and advances in sport science knowledge, but this knowledge is not being read by coaches, what use does it have? Of course, researching about a topic for the mere purpose of knowing, even if it does not have real world applications is legit, and must be done, as this can derive in different research lines in the future that will have application.

1.3.2 From Theory to Reality: When did science and practice take different paths?

In a study based on a transcription of a roundtable of the inaugural congress of the Australian Association for Exercise and Sports Science by Bishop et al. (2006)[105], participants were asked about what sport-science for them was, about the necessity of instant applicability of research and if the problem was due to the lack of communication abilities of the scientists.

Shortly, there was a clear differentiation on base sport-science and applied sport-science. The first was made for publication, and the applicability in field was secondary, while the last one was science made for application in coaching, and it may or may not be published. This difference was still present in the second question, where it was stated that the broad majority of coaches asked for rapid solutions, while less coaches were patient enough to wait for longitudinal studies or series of studies. These two questions stand out something: coaches think that studies should be more appliable and short-term oriented. But, as Dr. Robert Newton stated during that roundtable, important results cannot come out of nowhere, they need time and a series of preceding studies; asking only for short-term oriented studies does not make sense. Instead, coaches need patience and ability to interpret results and seek for application.

Even if coaches are patient, it is still the doubt if the problem relies on the lack of interpretation ability of coaches or poor communicating ability of scientists. As their name indicate, sport-scientists research around sport, that is, to improve performance, reduce injury risks, improve technologies… Thus, a good communication among the principal stakeholders is crucial, and researchers need to improve their communicating abilities as much as their research abilities[105].

This is why there are scientists that are not dedicated to research, but to interpretation of research for the less specialised public, as undergraduate students. This is of paramount importance, as nowadays social networks are used by everyone to obtain information. Based on www.statista.com , Facebook, Youtube and Instagram are 3 of the 4 most used social networks, with 2,910 million, 2,562 million and 1,478 million users in 2022. Everyone follows people or subjects in which are interested, and there is where scientists should come in. They should be there to fight misinformation and misinterpretation; they should be there to provide audience with quality information. Science is useless if it reaches nobody.

Dr. Carl Sagan believed that there was an urge to stop considering science as an elitist language, that science needed to be understood by everyone. Dr. Richard Feynman once said that if you cannot explain something in simple terms, you don´t understand it. These two great scientists believed in the necessity of communication skills, to make science available to anyone who needed it. Of course, there are scientific subjects and discussions that cannot be simplified enough to be understood by people without previous studies, and those subjects are inevitably reserved for the scientific community. Anyways, I still think that most of the people perceive science as an inaccessible field.

One of the main reasons why I decided to do my PhD was promoting the "scientific coach" figure. I strongly believe that scientists can be coaches or advisors if they are really interested, and coaches can (and should) be scientists, as they need to keep up with science to do their job the best they can. There is no need to publish papers by coaches if they do not want to, but at least they should be able to search, filter and read scientific studies. I am not pretending to disdain the importance of experience when coaching. Experience can be critical, especially when the sport involves difficult technical or tactical aspects. But what is clear is that there is a need for a bridge between science and practice, and promoting general public oriented divulgation could help. Specialised texts are needed and have their purpose; but as scientists, we should not forget that science, even if made by a small, specialised population, is meant for everyone, and should be as accessible as possible.

Thus, the starting point of this thesis was to try to remove as many biases as possible, as many misinterpretations as possible, and creating a document to which any strength, powerlifting or bodybuilding coach thinking to implement PAPE in their athletes´ training could go to. I have tried separating mere curiosity and non-applicable content (as physiological mechanisms) from the more applicable and field oriented (as different existing protocols and their possible uses), with the intention of easing the reading and facilitate finding what the reader is looking for.

2

HYPOTHESES & AIMS

The culture we have does not make people feel good about themselves. And you have to be strong enough to say if the culture doesn´t work, don´t buy it.

Mitch Albom – Tuesdays with Morrie

2. HYPOTHESES & AIMS

2.1. Hypothesis

In order to make this case 3 papers were planned. The first study was a systematic review of the scientific literature available on PAP and PAPE for strength sports, and it was performed to serve as an introduction. Following this we analysed the possible effect of an isometric PAPE protocol compared to a traditional PAPE protocol in high-loaded (85% 1RM) strength training, and its effects on sticking region kinematics. Finally, we analysed the effects of a high-loaded (93% 1RM) traditional PAPE protocol compared to a control group (no PAPE) on performed repetitions until volitional failure in a set of bench press, as a potential way to improve muscle mass adaptations. In essence, we analysed the possible application of a different contraction regime PAPE protocol, to increase the number of available useful protocols and the effect of a PAPE protocol in training volume. This was performed with the intention of expanding the number of available tools for coaches and strength training specialists.

2.2. Summary of Aims

- Examine the literature regarding Post-Activation Potentiation and Post-Activation Performance Enhancement (Publication 1)
- Examine the importance of volume and intensity in Post-Activation Potentiation and Post-Activation Performance Enhancement (Publication 1)
- Examine the effects of an isometric PAPE protocol compared to a traditional PAPE protocol (Publication 2)

- Examine the effects of an isometric and traditional protocol over the sticking region (Publication 2)
- Compare the performed volume in a training bout with and without a high-loaded traditional PAPE protocol (Publication 3)
- Compare the velocity loss during a training bout to volitional failure with and without a high-loaded traditional PAPE protocol (Publication 3)
- Explore why any potential discrepancies occurred (All Publications)

2.3 Specific Aims by Publication

2.3.1 Publication 1: Post-Activation Potentiation in Strength Training: A Systematic Review of the Scientific Literature

This publication was intended to introduce the concept of PAP and to clarify the potential importance of volume load and intensity in existing protocols. PAP is commonly used during the warm-up through complex training, which refers to a training method where heavy resistance exercises are used prior to a biomechanically similar ballistic movement[106].

Mainly, four conditions need to be considered to achieve a correct potentiation effect after a conditioning activity: (i) intensity to activate the working mechanisms[39], (ii) volume, which is inversely proportional to intensity, (iii) resting time, which is directly conditioned by intensity and volume[40] and (iv) movement similarity[107].

Very different protocols are used by strength coaches, and manipulation of above-mentioned variables are crucial. Thus, the aim of the first study was to compare different protocols and to clarify the importance of the aforementioned variables on the conditioning activity.

2.3.2 <u>Publication 2</u>: Intermittent Voluntary Isometric Contractions Effects on Performance Enhancement and Sticking Region Kinematics in the Bench Press

This publication was intended to compare the effectiveness of an isometric PAPE protocol compared to a traditional dynamic PAPE protocol. PAPE is commonly achieved with heavy resistance exercises (the conditioning activity) prior to performing a biomechanically similar movement and its magnitude and duration depend on several factors, including muscle fiber type, muscle temperature or sarcomere length. Some studies analysing isometric contractions as potentiation stimuli have been already performed involving lower limb exercises but show conflicting results.

Also, several different strategies have been proposed in the literature to face it, which include adding more load in that specific region using elastic bands or chains, and also by improving the impulse prior to the sticking region. Based on Lum and Barbosa [4] isometric strength training can produce strength improvements in joint angles up to 20º-50º away from the joint angles used during that isometric training.

Thus, the aims of this study were: i) to determine whether an isometric PAPE protocol is applicable to field conditions for the medium grip bench press and ii) observe if any changes occur in the kinematics of the sticking region due to the PAPE protocol.

2.3.3 <u>Publication 3</u>: Post-Activation Performance Enhancement as a strategy to improve bench press performance to volitional failure

Improving sport performance requires correctly combining different aspects through a training program. Several strategies are commonly used to improve acute force production in explosive tasks, being Post-Activation Performance Enhancement (PAPE) one of those strategies.

PAPE has gained notorious popularity in power related sports due to its capacity to improve acute rate of force development using different strategies with different muscle contraction regimes as conditioning stimuli. In addition, PAPE has started to be studied as an acute mechanism to improve the total volume performed during a training bout. Evidence so far seems contradictory and scarce, and the role of PAPE on training volume is yet to be elucidated.

Thus, this study aimed to analyse the influence of a traditional PAPE protocol on a set at 80% 1RM in the bench press performance, total work performed and last repetition kinematics in a training set to volitional failure in the bench press exercise.

3

METHODOLOGY

Dip a person into one particular specialty deeply enough and long enough, and he would automatically begin to assume that specialists in all other fields were magicians, judging the depth of their wisdom by the breadth of his own ignorance

Isaac Asimov – Stranger in Paradise

3. METHODOLOGY

3.1 Publication 1: Post-activation potentiation in strength training: A systematic review of the scientific literature

3.1.1 Experimental Approach to the Problem

A literature search was conducted on October 23, 2020. The following databases were searched: PubMed and Scopus. The previously named databases were searched from inception to October 2020, with language limitations: only peer reviewed articles in English were selected. Citations from scientific conferences were excluded.

3.1.2 Literature Search

In the database, the title and abstracts were searched. The following MeSH terms and key words, combined with the Boolean operators (AND, OR), were used: "athletic performance", "resistance training", "post activation potentiation", "PPA", "PAP", "post-activation potentiation", "potentiation post activation", "potentiation post-activation", "performance", "strength performance", "strength training", "strength" and "powerlifting". No additional filters or search limitations were used.

3.1.3 Inclusion Criteria

Studies were eligible for further analysis if the following inclusion criteria were met; a) subjects´ age ranged between 18-30 years; b) studies analysed experienced lifters; c) post-activation potentiation was studied in sports with high requirements of the rate of force development; d) the potentiation protocol was conducted with barbell exercises; e) pre- and post-evaluation was done with a resistance exercise, vertical jump or similar (i.e. squat jump, counter movement jump or drop jump). In the studies where volume was not directly reported, it was calculated as follows: volume = sets x repetitions x kilograms.

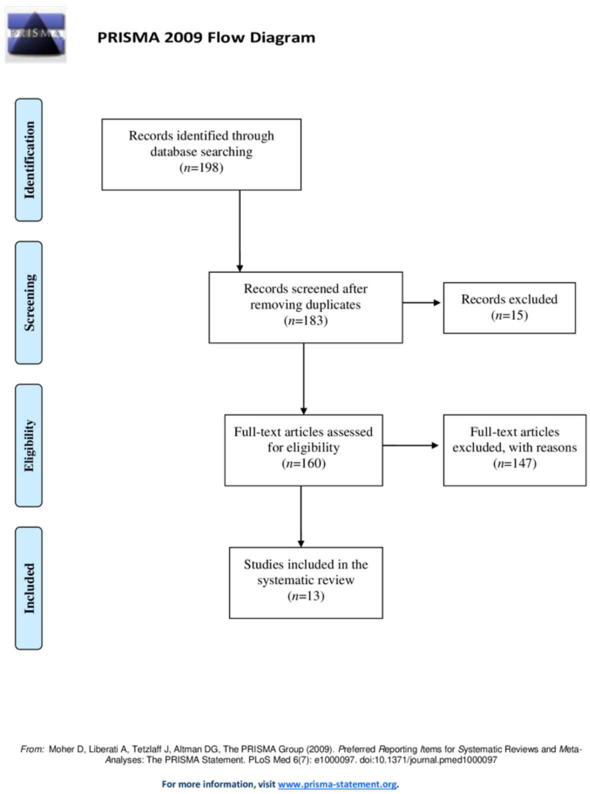


Figure 4. Flow chart of search strategy and selection of articles

3.1.4 Quality assessment

Oxford's level of evidence[108] and the Physiotherapy Evidence Database (PEDro) scale[109,110] were used in order to assess the methodological quality of the studies included in the review. Oxford's level of evidence ranges from 1a to 5, with 1a being systematic reviews of high-quality randomized controlled trials (RCT) and 5 being expert opinions. The PEDro scale consists of 11 different items related to the scientific rigor. Given that assessors are rarely blinded and that blinding participants is almost impossible, items 5-7 (which are specific to blinding) were removed from the scale[28]. With the removal of these items, the maximum result on the modified PEDro scale was 7 (the first item is not included in the final score) and the lowest, 0. Zero points are awarded to a study that fails to satisfy any of the included items and 7 points to a study that satisfies all the included items.

Table 1. Physiotherapy Evidence Database (PEDro) ratings and Oxford evidence levels of the included studies.

Study	1	2	3	4	5	6	7	8	**Total**	**Evidence level**
Andrews et al. (2016)	Yes	1	1	1	1	1	1	1	7	1b
Comyns et al. (2007)	Yes	1	1	1	1	1	1	1	7	1b
Dello Iacono et al. (2019)	Yes	1	1	1	1	1	1	1	7	1b
Do Carmo et al. (2018)	Yes	1	1	1	1	1	1	1	7	2b
Gilbert & Lees (2007)	Yes	1	1	1	1	1	1	1	7	1b
Golas et al. (2017)	Yes	1	1	1	1	1	1	1	5	2b
Kilduff et al. (2008)	Yes	0	0	1	1	1	1	1	5	2b
Kobal et al. (2019)	Yes	0	0	1	1	1	1	1	5	2b
Krzysztofik et al. (2020a)	Yes	1	1	1	1	1	1	1	7	1b
Krzysztofik et al. (2020b)	Yes	1	1	1	1	1	1	1	7	1b
Krzysztofik et al. (2020c)	Yes	1	1	1	1	1	1	1	7	1b
Krzysztofik and Wilk (2020)	Yes	1	1	1	1	1	1	1	7	1b
Lowery et al. (2012)	Yes	1	1	1	1	1	1	1	7	2b
Mina et al. (2019)	Yes	1	1	1	0	1	1	1	6	1b
Poulos et al. (2018)	Yes	1	1	1	1	1	1	1	7	1b
Reardon et al. (2014)	Yes	1	1	1	1	1	1	1	7	2b
Thomas et al. (2015)	Yes	1	0	0	1	1	1	1	5	2b

Items in the PEDro scale: 1 = eligibility criteria were specified; 2 = subjects were randomly allocated to groups; 3 = allocation was concealed; 4 = the groups were similar at baseline regarding the most important prognostic indicators; 5 = measures of 1 key outcome were obtained from 85% of subjects initially allocated to groups; 6 = all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least 1 key outcome were analysed by "intention to treat"; 7 = the results of between-group statistical comparisons are reported for at least 1 key outcome; 8= the study provides both point measures and measures of variability for at least 1 key outcome

3.2 Publication 2: Intermittent Voluntary Isometric Contractions Effects on Performance Enhancement and Sticking Region Kinematics in the Bench Press

3.2.1 Participants

Twenty-one participants (age 26.4 ± 5.4 years; body mass 79.4 ± 9.7 kg; body height 176.2 ± 6.9 cm; medium grip bench press 1 repetition maximum (1RM) 97.4 ± 19.8 kg; relative strength (1RM/body mass) 1.22 ± 1.9) with at least two years of resistance training experience voluntarily took part in this study. Participants were required to meet the following inclusion criteria: 1) men between the age of 18–40 years; 2) lack of musculoskeletal disorders or injury in the previous 6 months; 3) experienced in resistance training, defined as consistently lifting weights at least 3 times per week for a minimum of 2 years. A total of 20 participants completed the study: one participant dropped out prior to completion due to personal reasons. We did not control for nutrition nor hydration levels, but participants were told not to make any changes in the above during the testing period. Participants were asked to refrain from training 48 h before each testing session and not to take caffeine. All participants performed the three sessions at the same time of the day with at least 48 h of rest between sessions. Written informed consent was obtained from each participant after a thorough explanation of the testing protocol, the possible risks involved, and the right to terminate participation at will. The study was conducted according to the Declaration of Helsinki[111], and the Institutional Review Board of the University of the Basque Country (UPV/EHU) approved the experimental protocol.

3.2.2 Procedures

Participants visited the laboratory on three separated occasions. Prior to every experimental session and the 1RM test, participants performed a standardised warm-up protocol, consisting of 5 min of cycling and bench press warm-up sets consisting of 1 set of 12 repetitions with the barbell only, followed by 3 sets of 8, 6 and 3 repetitions with 40%, 60% and 75% 1RM, respectively. The rest interval between warm-up sets was to 2 min. In every session, during the bench press, participants performed the descent with a 2 s tempo, followed by a 1 s pause in the chest with help of a metronome at 60 beats per minute (BPM) to standardise repetitions. Participants were instructed to perform the concentric phase as fast as possible. Bench press grip width was set at 1.4 times biacromial distance as described elsewhere [89].

3.2.2.1 1RM calculation

During the first visit, participants underwent a direct 1RM test for the bench press. The 1RM was defined as the highest load lifted by participants without any compensatory movement and only if they completed the pause on the chest properly. When an attempt was successful, the next attempt was decided asking the participant and evaluating the reported mean propulsive velocity by the velocity linear (Speed4Lifts, Spain) [112]. Participants rested for 3 min between attempts. The test finished when participants reported a rate of perceived exertion (RPE) of 10 in the repetitions in the reserve based RPE scale [54]. If participants failed an attempt, the weight was reduced by 2.5 kg and another attempt was performed after a 3 min rest interval.

3.2.2.2 Sticking region identification

In addition, each lift on familiarization was recorded from a side view at 300 Hz using an active LED marker on the barbell's edge and a high-speed video camera (Casio ExilimEX-F1). Video recordings were analysed using kinematic analysis software Kinovea (version 0.8.15), which is valid, precise, and reliable [113]. Data exported from Kinovea to Excel (version 16.16.27) were filtered (Butterworth low pass filter at 5Hz) and then used to determine where the sticking region was, defined as the region of the lift between the first peak ($V_{max\ peak}$) in velocity and the first minimum after the peak ($V_{min\ peak}$) [114]. This region differs inter-individually due to differences in anatomical cross-sectional area of the muscle, force-length relationship, force-velocity relationship, fatigue, motor unit recruitment, fiber type and biomechanical factors that affect torque development [20].

Once the sticking region was detected, the height of the barbell at this region was calculated. Since the sticking region is not a specific point, but a range of motion of the lift, to ensure that the isometric contraction affected the sticking region, the protocol was performed in the middle of this region, as isometric contractions had been demonstrated to strengthen 20º-50º away from the adopted joint angles [4].

3.2.2.3 Conditioning Activities

Measurements of the experimental conditions lasted 45 minutes and were scheduled one week after the first visit to the laboratory. The study followed a within-participant design, where each participant was his own control. In this way, in both experimental sessions participants performed a pre-conditioning lift (control lift), a conditioning activity and several post-conditioning lifts. Thus, the second day, participants were randomly assigned to one of the following two experimental conditions: an isometric contraction conditioning protocol (ISO) or a traditional conditioning protocol (TRAD). Volume was not matched between conditioning activities. On the third session, participants changed experimental conditions. After completing the conditioning protocol (ISO or TRAD), participants were asked for RPE.

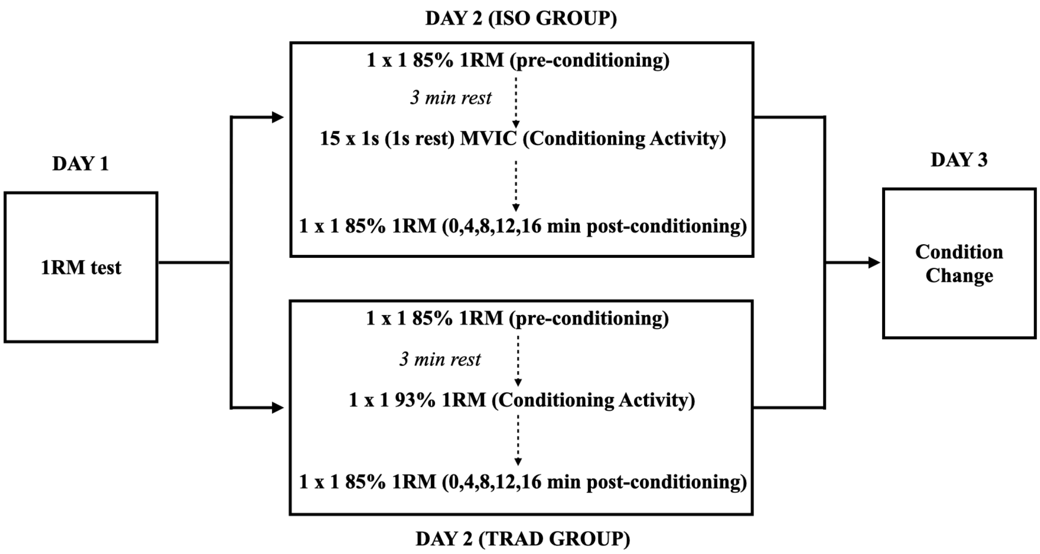


Figure 5. Scheme of followed investigation procedure

Each experimental session consisted of the standardised warm-up protocol followed by a 3-min rest interval and a pre-conditioning lift (control lift), which consisted of 1 set of 1 repetition of the bench press at 85% 1RM. After the pre-conditioning lift, participants rested 3 min and then they proceeded with the conditioning activity to which they were randomly assigned.

The ISO conditioning activity consisted of 15 maximal voluntary isometric contractions (MVIC) of 1 s with 1-s rest interval between contractions[5] at their sticking region as previously described. Participants were encouraged to exert force as fast as possible. Isometric contractions were performed by fixing the barbell of a Smith machine at the appropriate height (using a 11mm diameter rock climbing rope) to match the middle of the sticking region height. The TRAD conditioning activity consisted of 1 set of 1 repetition with 93% of their estimated 1RM of the familiarisation day[1].

Post-conditioning measurements (1 set of 1 repetition of the bench press at 85% 1RM) were recorded 0, 4, 8, 12 and 16 minutes later (post0, post4, post8, post12 and post16)[103,115] using the same velocity linear transducer. Participants were instructed to lift the barbell as fast as possible during the ascending phase of the movement.

If participants improved performance from pre-conditioning to any of the post-conditioning lifts, they were chosen for further analysis of the sticking region kinematics. This distinction between responders and non-responders to conditioning activity was based on the calculated smallest meaningful difference. When the difference in the best post-conditioning lift and the pre-conditioning lift was higher than the smallest meaningful difference, participants were considered responders and chosen for analysis of the sticking region.

3.2.3 Statistical Analyses

Data were screened for normality of distribution using the Shapiro-Wilk test. Two-way ANOVA with repeated measures (lift x time) was used to determine if any of the post-conditioning lifts improved performance under each experimental condition and to compare same time point across experimental conditions (ISO vs. TRAD). The magnitude of differences of effect sizes (ES) were calculated using Cohen's *d* [116] and interpreted as small (>0.2 and <0.6), moderate (≥0.6 and <1.2) and large (≥1.2 and <2) or very large (≥2) according to Hopkins et al. (2009) [117]. All statistical analyses were performed using Prism 9 for Mac. Significance for all analyses was set at $p < 0.05$. 95% confidence intervals are reported as 95% [Lower limit, Upper limit]. Additionally, for those participants for whom the conditioning activity improved performance (responders), the velocity until the first peak in velocity was measured and compared using one-way ANOVA with repeated measures (lift x time), comparing pre-conditioning velocity, post0 velocity and velocity of the fastest time point. To select those responders, we calculated the smallest meaningful difference following the formula below:

$$\sqrt{\frac{2 \cdot \sigma^2}{n}} \cdot \left(z_{1-\beta} + z_{1-\frac{\alpha}{2}}\right)$$

The reported results by the formula were smaller (e.g., measured smallest meaningful difference = 0.005 $m \cdot s^{-1}$) than values reported by the used velocity linear transducer (e.g., 0.23 $m \cdot s^{-1}$). Thus, if any participant improved performance in any post-conditioning lift (e.g., from 0.23 $m \cdot s^{-1}$ to 0.24 $m \cdot s^{-1}$), the difference must have been higher than the calculated smallest meaningful difference. We also performed a Fisher´s exact test to compare if there was a significant difference between the number of responders and non-responders to the conditioning activity in ISO and TRAD groups.

3.3 Publication 3: Post-Activation Performance Enhancement as a strategy to improve bench press performance to volitional failure

3.3.1 Participants

Fourteen participants (age 24.57 ± 2.7 years; body mass 77.47 ± 12.2 kg; body height 174.21 ± 7.4 cm; medium grip bench press 1 repetition maximum (1RM) 101.6 ± 25.8 kg) with at least 2 years of resistance training experience voluntarily took part in the study. Participants were required to meet the following inclusion criteria: 1) males between the age of 18 and 40 years; 2) lack of musculoskeletal disorders or injury in the previous 6 months; 3) resistance training experience, defined as consistently lifting weights at least 3 times per week for a minimum of 2 years. Fourteen participants met the inclusion criteria and were recruited for the study, from which a total of 14 completed the control protocol and 12 participants completed the experimental protocol. Written informed consent was obtained from each participant after a thorough explanation of the testing protocol, the possible risks involved, and the right to terminate participation at will. The study was conducted according to the Declaration of Helsinki, and the Institutional Review Board of the University of the Basque Country (Ref. CEISH 117/2019)

3.3.2 Design and Procedures

Participants visited the laboratory on three separated occasions. Prior to every experimental session, participants performed a standardised warm-up consisting of 5-min cycling on a cycloergometer and bench press sets including 10 repetitions with 40% 1RM, four repetitions with 60% 1RM, two repetitions with 70% 1RM and one repetition with 80% 1RM, as described elsewhere [6]. During the first visit, participants underwent a 1RM test for the medium grip bench press. The 1RM test was performed in the free weight bench press and grip width was set at 1.4 times biacromial distance as described elsewhere [89]. In every session, participants were requested to perform a 2-s tempo descent followed by a 1-s pause on the chest (using a metronome at 60 beats per minute) to standardise the repetitions [6]. The 1RM was defined as the highest load lifted by the participants without any compensatory movement only if participants completed the pause on the chest properly. When an attempt was successful, the next attempt was performed evaluating the reported mean propulsive velocity by the linear encoder T-Force Dynamic Measurement System (ERGOTECH, Murcia, Spain) [118].

After 72 hours, participants were randomly assigned (www.random.org) to a PAPE (experimental condition) or CON (control condition) group. The second and third experimental sessions were scheduled 72 hours apart to allow full recovery, and at the same time of the day. During the CON protocol, participants underwent the standardised warm-up, and 4 min after the last approximation set, they performed repetitions until concentric volitional failure with their 80% 1RM. During the PAPE protocol, participants underwent the same standardised warm-up, but they performed a heavy set of one repetition with their 93% 1RM as conditioning activity [1] and then were asked for their rate of perceived exertion (RPE). After the conditioning activity, participants rested for 6 minutes before performing repetitions until concentric volitional failure with their 80%

1RM. The conditioning activity settings (rest interval and the protocol used) were based on participants´ strength level. This configuration was chosen because participants´ strength levels (1.31 kg/kg) were closer to high strength levels reported by Cormier et al. (2022)[30] (≥1.35 kg/kg [1RM kg / body mass in kg] in the barbell bench press). Participants performed a 2-s tempo descent followed by a 1-s pause on the chest (using a metronome at 60 beats per minute) during all repetitions, to avoid compensatory movements and not to alter the obtained results. Mean propulsive velocity of the lifts was measured with the linear encoder T-Force Dynamic Measurement System. For the third session, participants changed the conditions. Participants were instructed to lift the barbell as fast as possible during the ascent of all testing lifts, and were requested not to perform any exhausting activity 48-hour prior to intervention. They were also encouraged not to consume caffeine or any other stimulant prior to testing.

3.3.3 Statistical Analysis

Data are presented as mean ± SD. All variables presented a normal distribution according to the Shapiro-Wilk test. A paired *t*-test was performed to compare the experimental with the control conditions. Additionally, the magnitude of differences of effect sizes (ES) were calculated using Cohen's *d* [116] and interpreted as small (>0.2 and <0.6), moderate (≥0.6 and <1.2) and large (≥1.2 and <2) or very large (≥2) according to the scale proposed by Hopkins et al. (2009) [117]. All statistical analyses were performed using Prism 9 for Mac. Significance for all analyses was set at $p<0.05$.

4

RESULTS

Nothing under Heaven is more important than education. The teaching of one virtuous person can influence many. What has been learnt by one generation can be passed on to a hundred

Kano Jigoro

4. RESULTS

4.1 Publication 1: Post-activation potentiation in strength training: A systematic review of the scientific literature

4.1.1 Studies Selected

The search strategy yielded 202 total citations as presented in Figure 1. From those 202 articles, 17 met the inclusion criteria. Excluded studies had at least one of the following characteristics: the potentiation protocol included strategies different from resistance training (e.g., electrostimulation or vibration), participants were not experienced lifters (had less than 2 years of resistance training experience or less than 2 x bodyweight squat 1-RM) or the evaluation protocol was done with sprinting bouts (Table 1).

4.1.2 Level of Evidence and Quality of the Studies

Ten of the seventeen included studies had a level of evidence 1b (good quality randomized control trials). The 7 remaining studies had a level of evidence of 2b (individual cohort studies). Also, the mean score in the PEDro scale was 6.47 ± 0.87, with values ranging from 5 to 7 (Table 1).

4.1.3 Characteristics of the Participants

Participants were characterized as experienced or well-trained athletes due to their training experience or their one repetition maximum (the maximum amount of weight that a person is able to lift for one repetition). A summary of participants´ characteristics is presented in Table 2. The total number of participants was 279 (253 men, 6 women and 20 unknown).

Table 2. Included studies

Study	Number (M/F)	Age (years)	RT experience (years)	Main Outcome
Andrews et al. (2016)	14 (8/6)	M 21.3 ± 1.8 / F 21.2 ± 0.4	≥ 2	Unilateral PAP and fatigue
Comyns et al. (2007)	12 (12/0)	23.3 ± 2.5	1RM ≥ 2x bodyweight	Optimal resistive load and PAP
Dello Iacono et al. (2019)	26 (26/0)	23.2 ± 5.1	≥ 2	Traditional sets PAP vs cluster sets PAP
Do Carmo et al. (2018)	12 (12/0)	25.4 ± 3.6	≥ 3	PAP rest interval
Gilbert and Lees (2007)	15 (15/0)	24.3 ±3.3	unknown	Changes in force development
Golas et al. (2017)	16 (16/0)	18-35	≥ 5	Used PAP load magnitude
Kilduff et al. (2008)	20 (Unknown)	25.4 ± 4.8	3.1 ± 1.6	Recovery time and PAP
Kobal et al. (2019)	18 (18/0)	25.42 ± 3.58	3	Different volume and PAP
Krzysztofik et al. (2020a)	12 (12/0)	25.2 ± 2.1	3	PAPE and training volume
Krzysztofik et al. (2020b)	32 (32/0)	28.4 ± 4.5	3	Eccentric and concentric PAP
Krzysztofik et al. (2020c)	13 (13/0)	25.7 ±1.9	6.5 ± 2.2	Eccentric PAP
Krzysztofik and Wilk (2020)	24 (24/0)	24.5 ± 2.6	6.3 ± 2.5	Plyometric PAP protocol
Lowery et al. (2012)	13 (13/0)	21 ± 3	3	PAP stimuli and recovery time
Mina et al. (2019)	15 (15/0)	21.7 ± 1.1	≥ 5	PAP: free weight vs variable resistance
Poulos et al. (2018)	15 (15/0)	24.3 ± 2.6	≥ 2	Back Squat intensity and PAP
Reardon (2014)	11 (11/0)	25.18 ± 3.60	1RM ≥ 2x bodyweight	Muscle architecture and PAP
Thomas et al. (2015)	11 (11/0)	23 ± 4	≥ 2	PAP and neuromuscular function

PAP = post activation potentiation; M = male; F = female; RT = resistance training

4.1.4 Studies matching volume load

Five of the included 17 studies matched the volume load in the protocols used. From these five studies, three compared different intensity protocols[103,115,119] and two the optimal rest interval[32,40].

Mina et al. (2019)[103] performed a study comparing free weight back squats and variable resistance back squats (elastic bands were used to generate the 35% of the total load at the upper part of the squat). Under the free weight condition, no significant changes were found in jump height, peak power or a normalized (to body weight) rate of force development (RFD) compared to pre-intervention performance. On the other hand, under the variable resistance condition, statistically significant increases ($p < 0.05$) in CMJ height were observed at 30s (5.9 ± 1.2%), 4 min (5.6 ± 1.8%), 8 min (6.5 ± 2.6%) and 12 min (5.3 ± 2.5%) compared to pre-intervention. In addition, statistically significant increases ($p < 0.05$) were evident in peak power at 30s (4.7 ± 1.2%), 4 min (5.9 ± 1.3%), 8 min (4.4 ± 1.7%) and 12 min (4.8 ± 1.7%) time points. These changes in CMJ height and peak power were also significantly different from the free weight condition group ($p < 0.05$).

Dello Iacono et al. (2019)[119] compared the effect of two protocols using the individualized optimal power load with traditional and cluster-set configuration in a randomized cross-over design. Although both protocols increased jump height 4 and 8 min post-intervention, the cluster set configuration reached significantly better results by 1.33 cm (95% CI, 1.02 to 1.65 cm) and 1.64 cm (95% CI, 1.41 to 1.88 cm), respectively.

Additionally, cluster set configuration was able to maintain 10% higher power output (95% CI, 8 to 12%) relative to their relative mean propulsive power.

Lowery et al. (2012)[115] studied the effects of three different loads (light, 56% 1RM; medium, 70% 1RM; and heavy, 93% 1RM) on vertical jump height. Vertical jumps after the light load protocol did not reach statistically significant differences. Moderate and high load protocols decreased vertical jump performance right after the conditioning activity ($p < 0.05$; $ES_{medium\ loaded} = -2.45$, large; $ES_{heavy\ loaded} = -2.87$, large). Additionally, a medium loaded protocol reached a significant performance increase at 4 min in the post activation training protocol ($p < 0.05$; ES = 1.46, large) and a high loaded protocol reached statistically significant improvements at both 4 and 8 min post protocol ($p < 0.05$; $ES_{4min} = 1.34$, large; $ES_{8min} = 1.48$, large).

Kilduff et al. (2008)[40] attempted to set the optimal recovery time for a complex training session. Participants performed 3 sets of 3 repetitions at 87% 1RM back squats before an explosive activity. They reported a statistically significant ($p < 0.05$) decrease at 15s post conditioning activity and a statistically significant ($p < 0.05$) increase at 8 min post conditioning activity for power output and for jump height. A statistically significant ($p < 0.05$) increase in the RFD 8 min post conditioning activity was also reported. Additionally, Do Carmo et al. (2018)[32] suggested that self-selected rest intervals were better than a fixed rest interval in order to dissipate the fatigue created by the conditioning activity. They conducted a study, and no significant changes were observed after the conditioning activity in the fixed rest interval group (38.0 ± 5 cm vs. 37.7 ± 5.1 cm; $p = 0.4$; ES = 0.04) nor in the self-selected rest interval group from pre- to post-test (38.2 ± 4.6 cm vs. 40.5 ± 4.4 cm).

4.1.5 Studies not matching volume load

The remaining twelve of the included 17 studies did not match the volume load in the protocols used. Four of these studies[6,38,41,120] support the relationship between a higher volume load and potentiation stimuli. Of the remaining 8 studies, one analysed the neuromuscular function[121], compared PAP in exercised and contralateral legs[122], compared the relationship between PAP and time under tension[50] and another studied the effects of plyometric PAP in bench press throw[123]. The remaining 4 reported contradictory results[39,106,124,125].

Four studies[6,38,41,120] support the notion of higher volume loads as better potentiation stimuli. These four studies compared different intensities and volumes ranging from 65% 1 RM to 130% 1 RM. Gilbert and Lees (2005)[38] found statistically significant increases in the isometric RFD in the 1RM group at 15 min (p = 0.021) and 20 min (p = 0.006), with a peak increase of 11.8%. In the optimal power load group, a statistically significant increase (p = 0.038) in the isometric RFD was found at 2 min, with a peak increase of 6.7%. Comyns et al. (2007)[120] found that contact time showed a statistically significant reduction ($p < 0.05$) and vertical leg spring stiffness indicated a significant increase ($p < 0.05$) for the heavy loaded protocol (93% 1RM). However, there were significantly ($p < 0.01$) shorter flight times for all the protocols. Krzysztofik et al. (2020)[6] compared the differences between a classic PAP protocol (2 sets of 2 repetitions of concentric bench press at 90% 1-RM) and eccentric protocols (2 sets of 2 repetitions of either only eccentric 90% 1-RM, only eccentric 110% 1-RM or only eccentric 130% 1-RM bench press). The study reported better potentiation results with eccentric only protocols, achieving greater peak velocity (η^2 = 0.441; p = 0.019) and greater mean velocity (η^2 = 0.011; p = 0.041) after the 110% 1-RM eccentric only protocol and greater peak velocity after the 130% 1-RM eccentric only protocol (η^2 = 0.323; p = 0.037). In another study by Krzysztofik et al. (2020)[41] with the same eccentric protocols, the bench press throw with a load of 30% 1-RM improved peak power by 10.5 ± 6.0% (effect size = 0.34) and by 9.9 ± 8.1% (effect size = 0.33) for the 110 and 130% 1-RM conditions, respectively. Peak velocity increased by 5.9 ± 5.5% (effect size = 0.4) and by 6.1 ± 6.1% (effect size 0.43) for the 100 and 130% 1-RM protocols, respectively. Since sets and repetitions remained the same through protocols, the differences in volume load were a result of the different intensities.

Four studies[39,106,124,125] showed conflicting results. In the study by Poulos et al. (2018)[106] both protocols (10 sets of 3 or 5 repetitions with 87% 1RM *vs*. 65% 1RM respectively) enhanced jump height (65% 1RM: +3.3 ± 2.2% [CI: 1.0 to 5.6]; 87% 1RM +2.6% ± 1.9% [CI: 0.7 to 4.5]) after 10 sets. Nevertheless, there was a larger chance of jump height improvement when CMJs were performed across the 10 sets of squats in the protocol of 87% 1RM. Golas et al. (2017)[39] compared five different protocols and they observed statistically significant (p = 0.01) differences in the RFD and the rate of power development (RPD) (p = 0.02) in the medium volume load group (80% 1RM) compared to the other conditions. Additionally, Kobal et al. (2019)[124] found that a lower volume load with a higher intensity (100% 1RM) protocol induced similar results to a higher volume load and lighter load protocol (93% 1RM and 87% 1RM). Reardon et al. (2014)[125] found no performance improvement in any of their protocols (3 sets of either 10 or 3 repetitions with 75% 1RM *vs*. 90% 1RM).

Thomas et al. (2017)[121] analysed neuromuscular function using EMG during a PAP protocol. Countermovement jump height increased significantly (p = 0.008) from pre- to post-potentiation (from 41.0 ± 4.3 cm to 44.7 ± 4.1 cm). Neuromuscular function was measured before the first CMJ and after the last CMJ. A small and statistically non-significant decrease in the maximum voluntary contraction (MVC) (p = 0.142) and in voluntary activation (p = 0.06) was observed, but potentiated twitch force was significantly (p < 0.001) reduced after strength training (235 ± 65 N to 185 ± 51 N) in comparison to the control group.

Andrews et al. (2016)[122] studied the effect of unilateral squats potentiation in the exercised leg and in the contralateral leg using a low fatigue protocol. The results showed no statistically significant differences at 1, 5 and 10 min in comparison to pre-test values for the drop jump contact time or the drop jump reactive strength index. Regarding the CMJ, a condition x time interaction indicated that the exercised leg exhibited significant but small to trivial magnitude jump height increases of 4.0% (p = 0.02; d = 0.36), 0.9% (p = 0.06; d = 0.08) and 1.6% (p = 0.04; d = 0.15) at 1, 5 and 10min post-intervention, respectively. The contralateral leg, on the other hand, had trivial CMJ deficits post intervention: 1.3% (p = 0.23; d = 0.12), 0.9% (p = 0.09; d = 0.10) and 1.7% (p = 0.03; d = 0.19) at 1, 5 and 10min post-intervention, respectively.

Krzysztofik and Wilk (2020)[123] showed that 3 sets of 5 repetitions of plyometric push ups with 1 min rest interval improved bench press peak velocity (p < 0.01) and mean velocity (p < 0.01) compared to a control group. In addition, Krzysztofik et al. (2020)[50] also found that a PAP protocol consisting of 3 sets of 3 repetitions at 85% 1-RM achieved higher training volume based on time under tension at the end of the training session (p < 0.01) when compared to a control group, despite completing the same number of repetitions.

4.2 Publication 2: Intermittent Voluntary Isometric Contractions Effects on Performance Enhancement and Sticking Region Kinematics in the Bench Press

4.2.1 Kinematics of the sticking region

To analyse the changes in the kinematics of the sticking region, subjects who improved performance in any time point (i.e., responders) were analysed, even if statistical significance was not reached. The Fisher´s exact test reported a significant difference between the number of responders and non-responders ($p = 0.001$). Thus, seven subjects were analysed for the TRAD condition and 17 for the ISO condition.

When comparing mean velocity from the start of the ascending phase until the first maximum peak in velocity (pre-sticking region), no differences were found in the TRAD experimental condition for the responders ($n = 7$; 33.33% of participants) ($p = 0.229$; 95% CI [−0.1545, 0.035]) (Figure 6A).

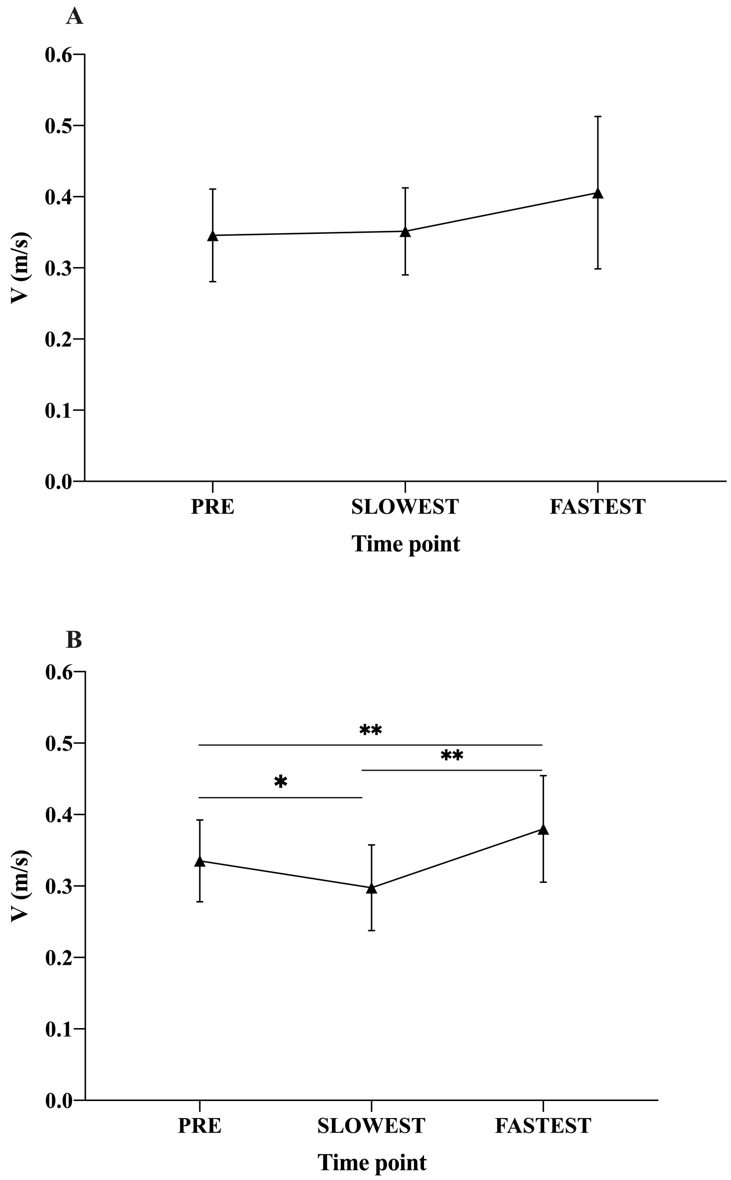


Figure 6 Lifting velocities pre-conditioning and in the slowest- and fastest post-conditioning activity time points. (A) TRAD post-activation performance enhancement experimental session. (B) ISO post-activation performance enhancement experimental session. * $p < 0.05$; ** $p < 0.001$

In contrast, when comparing the velocity from the start of the ascending phase until the first maximum peak in velocity under the ISO experimental condition in the same time points, we found that for responders (n = 17; 85% of participants), the first maximum peak in velocity was higher in the fastest time point (i.e., higher velocities were achieved prior to the initiation of the sticking region) ($p < 0.001$; ES = 0.67; 95% CI [0.07, 0.02]). However, when comparing the first maximum peak in velocity from pre- with the first maximum peak in velocity in the slowest time point (post0), we found that in the slowest time point, the first maximum peak was smaller (lower velocities were recorded prior to the initiation of the sticking region) ($p = 0.004$; ES = 0.64; 95% CI [-0.012, -0.063]). Additionally, the ascending phase velocity until the first maximum peak in the fastest time point was higher than in the post0 time point ($p < 0.0001$; ES = 1.22; 95% CI [0.112, 0.053]) (Figure 6B).

We compared $V_{max\ peak}$ and $V_{min\ peak}$ from pre- to the fastest post-conditioning lift of each participant for whom either the TRAD or the ISO experimental condition was effective. The TRAD experimental condition showed no improvements in $V_{max\ peak}$ ($p = 0.457$; ES = 0.37; 95% CI [-0.074, 0.146]) nor in $V_{min\ peak}$ ($p = 0.125$; ES = 0.85; 95% CI [-0.0271, 0.173]), while the ISO experimental condition showed improvements in both $V_{max\ peak}$ ($p = 0.005$; ES = 0.71; 95% CI [0.02, 0.093]) and $V_{min\ peak}$ ($p = 0.025$; ES = 0.38; 95% CI [0.006, 0.072]) (Figures 7A–D).

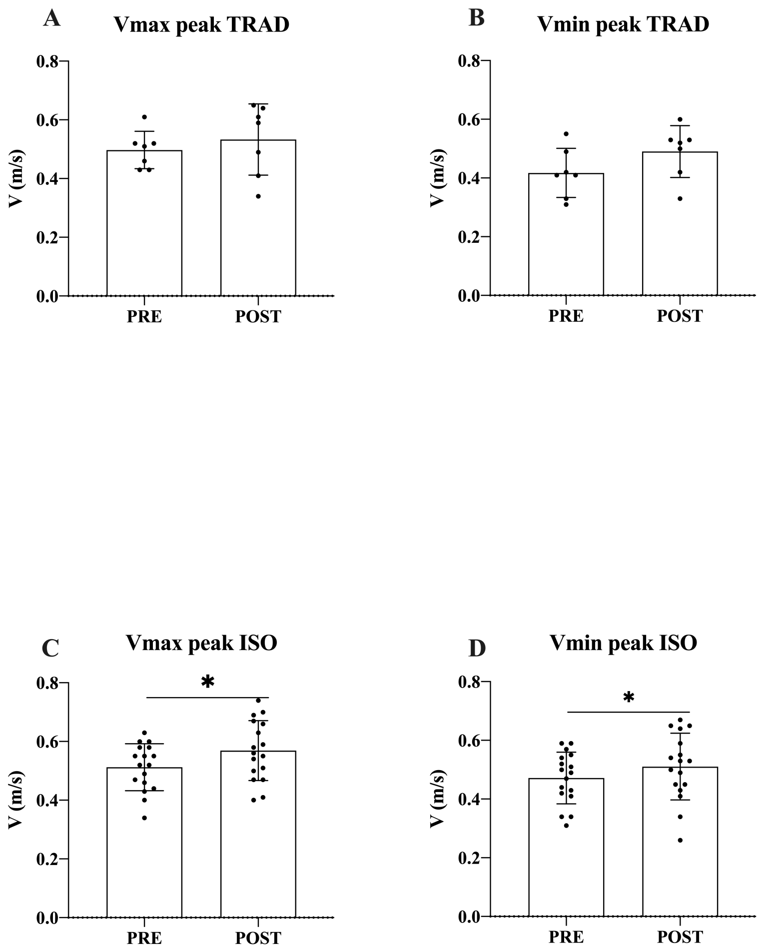
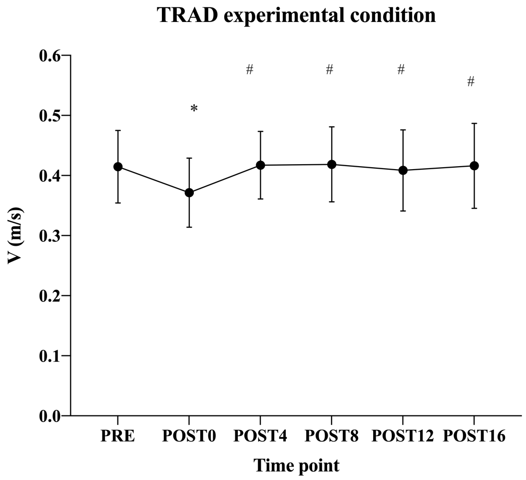


Figure 7 (A) first peak in the velocity of the load (V_{max}) in pre- and the fastest post-conditioning lift in TRAD. (B) First local minimum velocity peak (V_{min}) in pre- and the fastest post-conditioning lift in TRAD. (C) $V_{max\ peak}$ in pre- and the fastest post-conditioning lift in ISO. (D) $V_{min\ peak}$ in pre- and the fastest post-conditioning lift in ISO. $*p < 0.05$

4.2.2 Mean velocity changes and RPE

When comparing the mean propulsive velocity between pre- and all post-conditioning lifts, we found that post0 was slower than pre- in both TRAD ($p = 0.002$; ES = 0.74; 95% CI [-0.0136, -0.073]) (Figure 8A) and ISO experimental conditions ($p < 0.001$; ES = 1.53; 95% CI [-0.067, -0.153]) (Figure 8B). The TRAD protocol reported an average RPE (rate of perceived exertion) of 7.3 ± 0.7, while the ISO protocol reported an average RPE reported of 7.0 ± 1.0. None of the post- measurements reached statistical significance compared to pre- conditioning measurement. When comparing the same time points across experimental conditions (ISO *vs.* TRAD), there was only a significant result in post0, where the ISO condition induced slower performance than the TRAD condition ($0.37\ m{\cdot}s^{-1}$ vs. $0.3\ m{\cdot}s^{-1}$; $p = 0.01$; ES = 1.07; 95% CI [0.01219, 0.01217]).

A



B

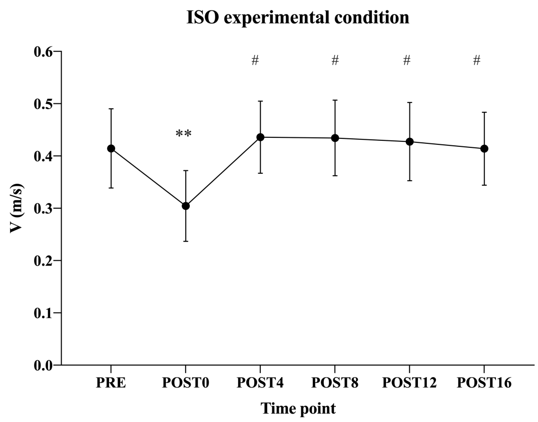


Figure 8 Lifting velocities pre and post 0, 4, 8, 12 and 16 minutes. (A) Mean TRAD post-activation performance enhancement experimental session values. (B) Mean ISO post-activation performance enhancement experimental session. Significantly different from pre * ($p < 0.05$) or ** ($p < 0.001$) and #post0 ($p < 0.001$)

4.3 <u>Publication 3:</u> Post-Activation Performance Enhancement as a strategy to improve bench press performance to volitional failure

When comparing the number of repetitions performed until concentric volitional failure in a set with 80% of the 1RM, participants performed significantly more repetitions (10.83 ± 2.5 repetitions) under the PAPE condition than under the CON condition (9.76 ± 1.72 repetitions) ($p = 0.008$; ES=0.5, small effect) (Figure 9).

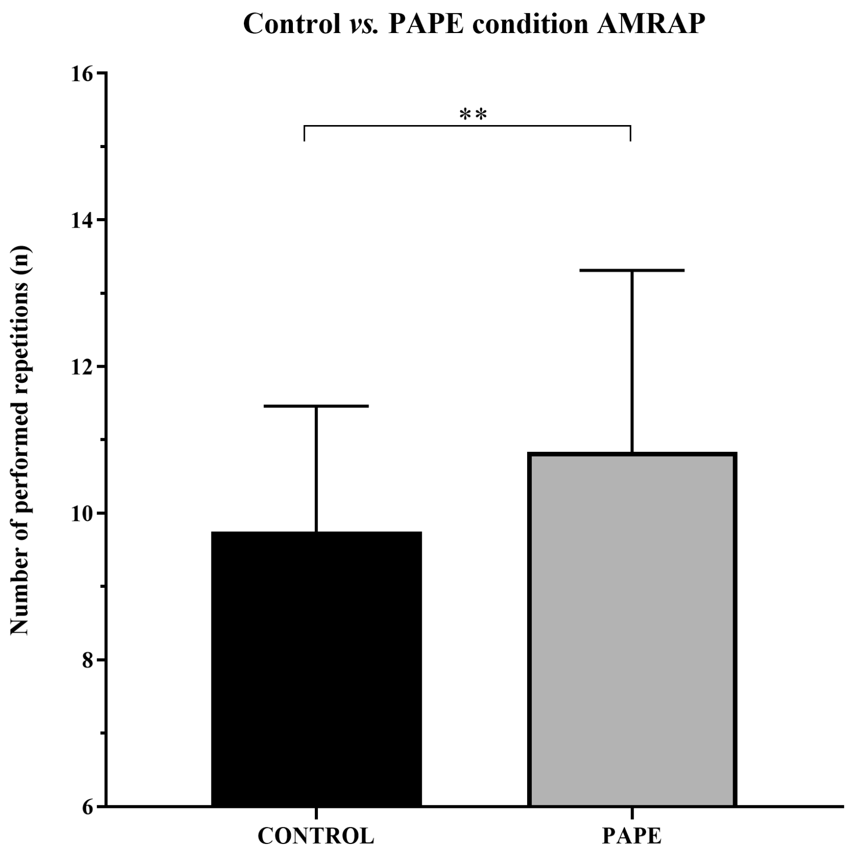


Figure 9 Total number of performed repetitions until volitional failure with the 80% 1RM in the CON (control) and PAPE (experimental) conditions. ** $p < 0.001$

The mean propulsive velocity of the last repetition prior to the concentric volitional failure was significantly lower under the PAPE condition (0.16 ± 0.06 $m \cdot s^{-1}$) than the

CON condition (0.2 ± 0.09 m·s^{-1}) ($p=0.02$; ES=0.52, small effect) (Figure 10). No differences were found in mean propulsive velocity of the first repetition between the PAPE condition (0.43 ± 0.1 m·s^{-1}) and the CON condition (0.42 ± 0.13 m·s^{-1}) ($p=0.582$; ES=0.09, small effect). Velocity loss from the first to the last repetition was significantly greater under the PAPE condition (0.27 ± 0.05 m·s^{-1}) compared to the CON condition (0.22 ± 0.08 m·s^{-1}) ($p=0.004$; ES=0.75, moderate effect).

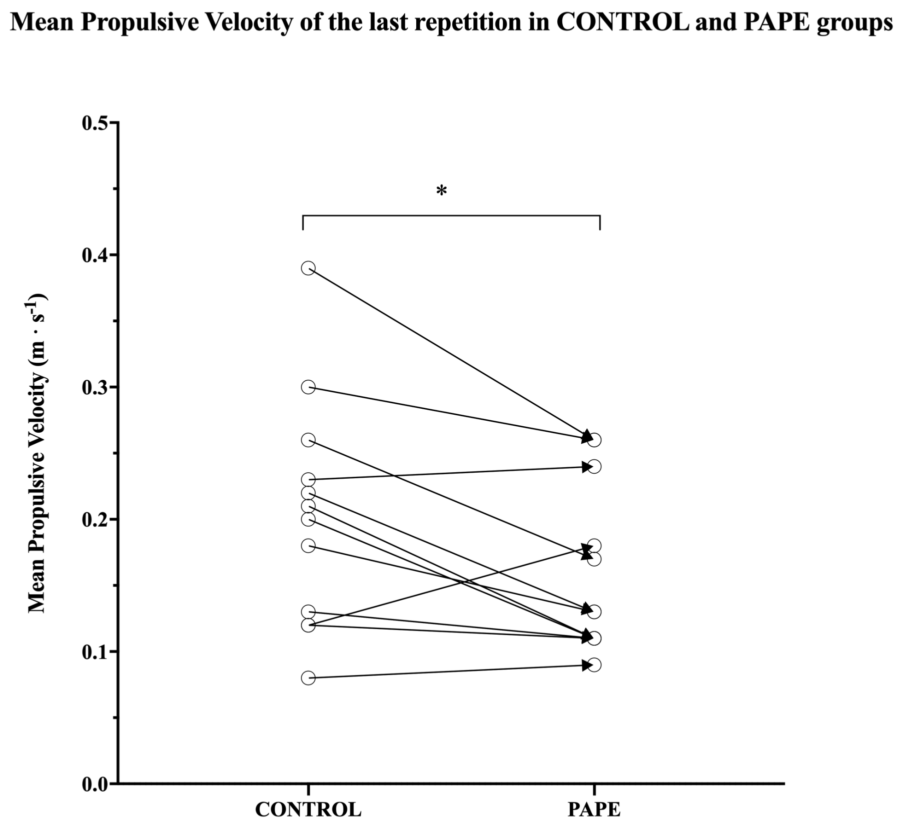


Figure 10 Mean propulsive velocity (m·s^{-1}) of the last repetition of the performed set to volitional failure with the 80% 1RM in the CON (control) and PAPE (experimental) conditions. *$p < 0.05$

The average reported RPE under the PAPE condition for the conditioning activity was 7.17 ± 0.58, and the achieved mean propulsive velocity in the conditioning activity was 0.30 ± 0.12 m·s^{-1}.

5

DISCUSSION

One, remember to look up at the stars and not down at your feet. Two, never give up work. Work gives you meaning and purpose, and life is empty without it. Three, if you are lucky enough to find love, remember it is there and don´t throw it away

Stephen Hawking – Interview on ABC´s World News Tonight

5. DISCUSSION

5.1 <u>Publication 1:</u> Post-activation potentiation in strength training: A systematic review of the scientific literature

The main finding of this systematic review is that the volume load plays an important role in performance enhancement after a conditioning activity. Four studies firmly support that the volume load is the main conditioning factor to achieve an optimal potentiation effect[6,38,41,120], while four showed contradictory results[39,106,124,125]. This systematic review also shows that when the total volume is low, intensity seems to be decisive[106,122].

Recruitment of type II fibers is needed to achieve potentiation, which is the result of combining volume and intensity[126–129]. As stated by Schoenfeld (2010)[22], in order to recruit high order motor units, light loads are not as effective as heavy loads. In the four studies[6,38,41,120] firmly supporting our hypothesis, high intensities were used (up to 130% 1 RM) to achieve higher volume loads. However, potentiation can be achieved using lower volume loads as well[39,124]. Gołas et al. (2017)[39] and Kobal et al. (2019)[124] performed between 3 and 5 sets with different loads ranging from 60% 1 RM to 100% 1-RM with a fixed rest interval. Considering that fatigue is especially evident when training is performed close to 1-RM or to failure[26,130], the better potentiation achieved in these studies with lower volume loads may rely on the rest-time between the conditioning activity and the re-test. Although according to Do Carmo et al. (2018)[32] a self-selected rest may be sufficient to improve performance, other studies suggest that potentiation values peak after 8 min or longer resting periods[38,40].

The second finding is that a minimum effective intensity is needed to achieve potentiation. However, intensity should be understood as the number of repetitions in reserve and not as the percentage of 1-RM. In order to achieve potentiation, we can either use light loads with high volumes or high intensities with low volumes[127]. Thus, when leaving at least 2 repetitions in reserve, performing multiple sets leads to potentiation without accumulating excessive fatigue[106,122]. However, although lowering intensity during the conditioning activity may lead to lesser fatigue[103], leaving too many repetitions in reserve may not provide enough stimuli to elicit potentiation[54,125]. On the other hand, leaving too few repetitions in reserve (between 0 and 1) may lead to excessive fatigue and impaired performance after the conditioning activity [54,125]. In this way, the higher the intensity, the longer the rest interval the athlete needs to dissipate fatigue[32,38].

We also found different time-potentiation profiles for high- and medium-load protocols. In the study by Lowery et al. (2012)[115], heavy and medium protocols peaked at the same time point, but potentiation achieved with the heavy loaded protocol was maintained for a longer time. These findings are in line with those of Gilbert and Lees (2005)[38], who reported different time-potentiation profiles; while the optimal power load group peaked earlier, the heavy loaded protocol group peaked later but with a higher potentiation effect (6.7% *vs*. 11.8%, respectively). These findings are in line with those by Krzysztofik and Wilk (2020)[123], who observed the greater increase in peak velocity and mean velocity of the bench press in the first set after the plyometric push ups protocol. Thus, the time-potentiation profiles seem to be determined by the intensity of the stimuli and the resting time (fatigue-potentiation relationship). Fatigue in resistance training, as suggested by Zajac et al. (2015)[130], is produced by post-exercise intramuscular perturbations (i.e., decrease in phosphocreatine, glycogen, ATP stores and augmentation of phosphate and hydrogen ions) and modulation of central motor drive during exercise by nociceptive afferent input (III and IV muscle afferents). These changes are especially evident when training sessions are close to 1-RM. During submaximal contractions, the closer to failure, the more motor units are recruited, but also the higher the metabolite accumulation, which contributes to fatigue[26]. This may partially explain the differences in the potentiation protocols leaving too many[122] or too little[125] repetitions in reserve during submaximal efforts.

We have to acknowledge several limitations. These include the lack of raw data for a deeper analysis. The main purpose of the review was to summarize the evidence so far and, if possible, to analyse differences in used protocols based on the volume load. While the most recent studies included raw data, the oldest ones did not. This limited our intention to compare the volume load of different protocols as we could not calculate it for 2 of the 13 studies. Another important limitation was related to the heterogeneity of the protocols used. Finally, the results of this review cannot be extrapolated to the general population as it only analysed trained subjects and almost all subjects were men. All these limitations imply that the conclusions of this review should be interpreted with caution.

5.2 Publication 2: Intermittent Voluntary Isometric Contractions Effects on Performance Enhancement and Sticking Region Kinematics in the Bench Press

The findings of this study support one of our two hypotheses, i.e., the kinematics and the characteristics of the sticking region change considerably (Figure 11 A-C) after the ISO conditioning protocol, however, mean propulsive velocity remains unchanged.

The main finding of this study was that an isometric PAPE protocol improved sticking region kinematics in the first part of the range of motion of the medium grip bench press. This improvement is evident in the first period of the ascending phase, prior to the sticking region, which helps the lifter to overcome that sticking region [20]. The main enhancement is that the first maximum velocity peak is greater after the ISO conditioning protocol (Figure 7C), which provides the lifter with a greater impulse to overcome the sticking region. Also, the minimum velocity is higher after the ISO conditioning protocol (Figure 7D). The augmented first maximum and minimum velocity peaks result in a change in the velocity-time profile of the lift (Figure 11 A-C). This change in the velocity-time profile of the lift and the sticking region (i.e., less velocity loss from maximum to minimum velocity points) is due to the greater impulse that the lifter has achieved prior to the sticking region. The improvement in the first part of the lift can provide the lifter with enough impulse to avoid excessive velocity loss from $V_{max\ peak}$ to $V_{min\ peak}$, making the sticking region imperceptible (Figure 11C).

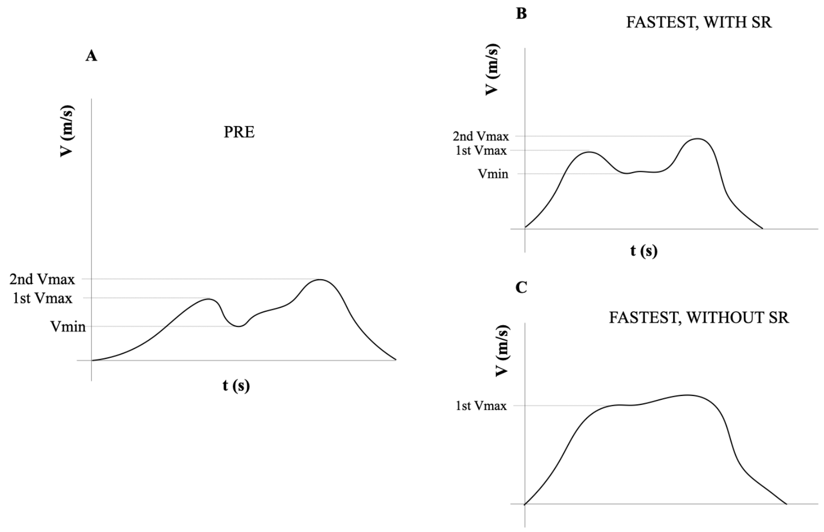


Figure 11. (A) Illustration of a typical Sticking Region velocity-time profile, which could be observed in pre-conditioning lifts. (B) Illustration of a Sticking Region velocity-time profile post-conditioning, with enhanced the first peak in the velocity of the load (V_{max}) and its first local minimum peak thereafter (V_{min}). (C) Illustration of a post-conditioning lift where the impulse prior to the initiation of the Sticking Region is augmented to the point that no velocity loss occurs and, thus, V_{min} disappears.

The ISO conditioning protocol improved performance in more participants (85%) than the traditional conditioning protocol (33.33%), which could be related to the interaction between stimuli and fatigue [17]. Recruitment of type II fibers is needed to achieve PAPE, which is the result of a correct selection of intensity [1]. The TRAD conditioning protocol implied a higher RPE than the ISO conditioning protocol (ES = 0.36). Nonetheless, in both conditioning protocols participants reported an RPE 7, which is in line with previous literature [1]. The ISO conditioning protocol includes 1-second rest intervals, which via the reduction in inorganic phosphate accumulation could help reduce excessive fatigue [5].

Is worth mentioning that the ISO conditioning protocol produced greater decrease in performance immediately post conditioning (post0) compared to the TRAD protocol. This could be due to the total time under tension, which is greater in the ISO conditioning protocol (15-seconds in total). However, in contrast to the TRAD conditioning protocol, improvements in velocity until the initiation of the sticking region were found in the ISO conditioning protocol, which suggests that isometric contractions produce less fatigue than dynamic contractions, or that subjects recover from the produced fatigue faster [4]. This lower cumulative fatigue may be due to the lower consumption of ATP in lengthened and isometric contractions compared to shortening contractions[131]. Regarding the neural factors limiting maximal force production, it is widely accepted that motor unit recruitment strategies play a key role [132]. The origin of this central fatigue could be at spinal level, due to inhibitory intramuscular afferents (i.e., group Ia and II muscle afferents) and recurrent inhibition by Renshaw cells [133].

We must acknowledge some limitations. Considering that a linear encoder provides the mean propulsive velocity [134] and that the minimum mean propulsive velocity for a successful lift on the bench press has been calculated [18], more velocity implies more distance from that mean minimum propulsive velocity, and thus, furthers subjects from failure. Unfortunately, changes in magnitude (e.g., from 0.27 $m{\cdot}s^{-1}$ to 0.29 $m{\cdot}s^{-1}$) were so small that statistical significance was not reached. Nevertheless, when comparing instantaneous velocities, magnitude changes were greater (e.g., from 0.26 $m{\cdot}s^{-1}$ to 0.34 $m{\cdot}s^{-1}$). Also, the selected intensity for the control lift (85% 1RM) was high. Even if notorious mean propulsive velocity changes are hard to see at those intensities, 85% 1RM was chosen for two main reasons: (i) higher similarity to a real strength training or competition and (ii) this is the minimum intensity needed to record a sticking region [96], which was one of the intentions of the study. Finally, it is worth mentioning that this study does not include a classic control group with no conditioning activity carried out. These limitations imply that conclusions of this study should be interpreted with caution.

5.3 Publication 3: Post-Activation Performance Enhancement as a strategy to improve bench press performance to volitional failure

The main finding of this study was that performing a traditional PAPE protocol consisting of a single set of a single repetition with the 93% 1RM [1] improved bench press performance, measured as number of repetitions to volitional failure. These results are in agreement with previous research [49].

Performing a traditional PAPE protocol prior to a set to volitional failure could make the athlete acutely more resistant to fatigue in long-lasting tasks (in our case, a set to volitional failure of various repetitions) [127]. The exact rationale behind this improvement in performance is not fully elucidated. Temperature raises are a commonly mentioned mechanism behind performance enhancement, but based on the results of Weigert et al. (2018) [81], where small and non-significant temperature changes were seen after 10 repetitions at 70% in a biceps curl, it seems unlikely. Nevertheless, Boullosa et al. (2018)[82] mention a possible mechanism, where the elevation of Ca^{2+} levels increase due to low-frequency twitches, what can cause the performance enhancement independent of myosin regulatory light chain phosphorylation.

Interestingly, performance improvements observed in this study may be related to improved capacity to perform slower repetitions, as under the PAPE condition, participants performed, on average, one more repetition, which was slower than under the CON condition (Figure 10). In consequence, the velocity loss was greater from the first to the last repetition. The attempt to complete one more repetition so close to failure could be due to psychological reasons[47]. The maximal adaptability theory[47] states that hyperstress situations could lead to bad performance. In this way, those last, hard, and slow repetitions would be the stressing situations where participants need to strive to fulfil the lift. Performing the conditioning activity in the PAPE protocol (a heavy repetition prior to the tested task), could improve participants′ confidence when struggling with those last repetitions [47]. Another possible explanation for the performance improvement observed could be the training velocity specificity, which means that after performing that specific conditioning activity, participants gain acute fitness or adapt acutely to low velocity lifting [135].

The quantity of work performed per session, understood as total number of sets [27], or the volume load (sets x repetitions x kilogram) [136] is related to the quantity of gained muscle mass. Thus, if PAPE leads to an increased number of repetitions performed until failure, volume load per session would be improved, and so could muscle hypertrophy. Following this line of reasoning, it could also be assumed that hypothetic muscle hypertrophy benefits could be due to both the improved mechanical tension of the last repetition (due to obtained lower mean propulsive velocities, Figure 10) and a greater number of performed repetitions (Figure 9). This means that the performed additional repetition may be effective when aiming at muscle hypertrophy. Previous studies support the notion that with a greater velocity loss, muscle hypertrophy gains can be more significant [134], but only to some extent [137,138]. Evidence suggests that when velocity loss is excessive (40%), subsequent sets could be affected[138]. This is in line with findings of Alves et al. (2019)[49], where significant differences were found in the number of repetitions performed in the first (PAP = 11.5 ± 3.1; CON = 10.4 ± 2.7; $p < 0.05$; ES = 0.38) and the second (PAP = 6.5 ± 1.9; CON = 5.5 ± 1.8; $p < 0.05$; ES = 0.54) set between PAP and CON groups, but not in the third set. This suggests that performance enhancements can increase training volume significantly, but when velocity loss is too pronounced, fatigue may overcome potentiation and impair performance in subsequent sets. Our study is in line with that by Krzysztofik, Wilk, Filip, et al. (2020)[50], as increasing the number of repetitions led to higher time under tension. Based on this, future research should address whether a group performing a PAPE protocol combined with a moderate velocity loss (i.e., 20% velocity loss) can complete more repetitions than a control group for several sets (four to six sets). Furthermore, if the PAPE experimental condition group can perform more repetitions, it would be interesting to carry out a long-term intervention to examine whether this protocol would bring more muscle mass gain than a control condition.

This study faced several limitations, including relatively small (*n*=12) sample size, which make it difficult to generalise the obtained results. Our results prove that a PAPE protocol can be useful to improve performance in a task to failure, which makes PAPE a potential strategy to increase muscle hypertrophy gains. However, this was not measured, and therefore, further studies are warranted. Furthermore, our study included only one set until volitional failure, however, the effect of this set on performance in subsequent sets was not evaluated.

5.4 General Discussion

5.4.1 General concepts

Considering all the information above, the basis for any PAP or PAPE protocol are both intensity and volume. This is not unexpected, because if manipulation of those two concepts is of paramount importance when creating a training stimulus of any duration (a session, microcycle, mesocycle, macrocycle or any length cycle)[16,17], why should it be different when considering shorter time periods? Thus, when trying to achieve a correct PAP or PAPE stimulus during a warm-up, the goal should be focused on properly combining a certain volume load (sets · repetitions · kilograms or pounds)[1] with an appropriate rest interval.

To correctly achieve a potentiation effect from a PAP or PAPE protocol, recruitment of type II fibers is needed, and this can be done either using high intensities[22] or low intensities close to muscle failure[26]. As type II fibers are more sensitive to calcium, athletes with higher proportion of type II fibers will benefit more from high intensity (PAP or PAPE protocols where high forces are exerted) protocols[59]. Considering that fiber type percentage is not fully inherited[139] and that training background can have a huge impact on it[140], interindividual differences in response magnitude of the protocol are common. In any case, proximity to failure (understood as at least an RPE 6 in the repetitions in reserve based RPE scale[54]) is needed to recruit type II fibers [128,141]. As this intensity need can be fulfilled in two different ways, is there any difference in a protocol based on intensity or based on volume?

In the study by Lowery et al. (2012)[115] the medium load protocol (70% 1RM) improved performance 4 min post conditioning activity ($p < 0.05$; ES = 1.46, large), while the high load protocol (93% 1RM) achieved peak performance 4 and 8 min post conditioning activity ($p < 0.05$; $ES_{4min} = 1.34$; $ES_{8min} = 1.48$, large). These results are supported by Gilbert and Lees (2005)[38], where increases in the isometric RFD were seen at two different time points for each group. The 1RM group (high intensity group) improved

RFD 15 min (p = 0.021) and 20 min (p = 0.006) post conditioning activity, while the optimal power loaded group improved RFD 2 min (p = 0.038) post conditioning activity. Additionally, it has been shown that plyometric contraction-based protocols and heavy intensity protocols result in better performance enhancement than medium or low intensity protocols[31].

We can see that those protocols yielding better results are close to the 1RM or seeking high rates of power (as plyometric contractions). It seems reasonable, as based on force-velocity relationships, we can achieve maximal force either using high loads and slow lifting velocities or low loads and high lifting velocities[142]. This statement is based on the force formula:

$$F = m \cdot a$$

If the lifted mass is high (close to the 1RM), the product will be a high exerted force. It is worth mentioning that when experienced lifters perform a high-loaded lift, they perform it slowly due to the proximity to the 1RM, even if they try to perform the lift as fast as possible[104]. On the other hand, if the lifted mass is low, the possibility to apply high acceleration will be high, what will result in a high exerted force.

Another trend can be seen, the higher the used intensity (proximity to muscle failure), the higher the needed rest until peak performance. The closer to muscle failure, the higher the achieved mechanical tension[57], thus a greater disruption is caused in cell homeostasis and higher the needed rest. In plyometric contractions-based protocols, full motor unit recruitment is achieved due to exerted high forces, but cross-bridge formation is hindered and consequently, high mechanical tension cannot happen[143]. This could explain why in both type of protocols the time-potentiation profile (i.e., the needed rest time from conditioning activity to peak performance) differs, even when in both cases maximal force is exerted. An important point to consider is that most studies are performed using a PAP or PAPE protocol to test its effectiveness in a low load activity (such as running[107], jumping[115] or throwing[41]). High load protocols can improve performance in this type of tasks due to an improved RFD, as positive associations between maximal force and increased RFD have been documented[144]. Also, low-loaded high-velocity training and high-loaded low-velocity training seem to improve RFD[104]. This, combined with velocity specifity[135] training adaptations could explain why low-loaded protocols improve performance.

Considering that any PAP or PAPE protocol can be treated as an acute fitness-fatigue model, could produced fatigue be minimised while maintaining the fitness effect? In a study by Dello Iacono et al. (2019)[119], authors highlight the importance of carefully managing the fatigue and fitness effect produced by the PAP or PAPE protocol. With this purpose, they compared a traditional (3 sets of 6 repetitions) and a cluster-set configuration (3 sets of 6 repetitions with 20 seconds rest between 2 repetitions) PAP protocols, finding out that both protocols presented very similar time-potentiation profiles, but the cluster-set protocol group performed better in all post-test measurements. This suggests that accumulated fatigue was lower in the cluster-set group, and thus, the fitness effect was higher.

Considering all this information, it seems reasonable to think that each PAP or PAPE protocol has its own time-potentiation profile, principally determined by:

- Athlete´s training background (what will determine his or her fiber type proportion to a large extent)
- Used exercise as conditioning activity (if type II fibers are more sensitive to PAP or PAPE protocols, coaches should try to perform an exercise targeting muscles with high type II fiber proportion)[145,146]
- Used intensity (understood as a combination between % 1RM and proximity to volitional failure)
- Used volume (understood as performed repetitions and sets)

5.4.2 PAPE protocols for heavy lifting

As mentioned before, PAP and PAPE protocols are usually tested with ballistic movements, following a scheme like the following:

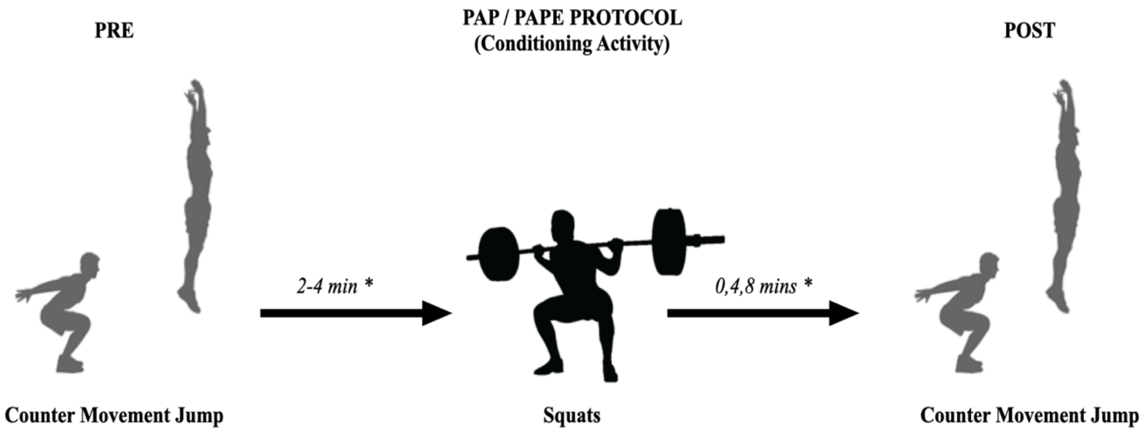


Figure 12. Representation of a typical research design for a PAPE protocol. In a PAP protocol study, twitch verification is needed. *These rest intervals are determined by researchers to fit with their hypotheses

Exercise selection in figure 12 can vary, but the structure remains the same:

- Ballistic exercise as pre- and post-test, to perform intra-subject comparisons. In figure 5 is depicted a CMJ, but this could be a bench press throw, a horizontal jump, light-loaded and low repetition lifting (2-3 repetitions with 60% 1RM) or even non-ballistic but light loaded exercises such as sprinting.
- The conditioning activity. This is the used exercise and protocol to induce PAP or PAPE.

- Rest intervals are fixed by researchers leading the investigation, and this rest intervals are usually based on literature and in accordance with the tested hypothesis.

As most of the studies test PAP or PAPE protocols in light-loaded or ballistic exercises, the purpose of this thesis was to study if there is any real applicability to heavy lifting sessions (i.e., replacing ballistic test-retest activities for high intensity lifts), such as powerlifting meets.

Powerlifting is a maximum strength sport where three compound movements are tested: the back squat, the bench press and the deadlift (sumo, semi-sumo or conventional)[147]. The nature of a powerlifting meet is similar to the direct measurement of a 1RM in those exercises, and therefore, dynamic protocols seem a poor strategy in this particular case for several reasons:

- They are time consuming (there is not much time to warm-up in a powerlifting meet)
- A PAPE protocol based on several sets and moderate loads (3 sets of 6 repetitions at 70% 1RM for example) is very light, as usually the first attempt of a powerlifting meet is around 85-90% 1RM
- A high intensity PAPE protocol (as 1 set of 1 repetition at 93% 1RM) is the same as performing the first or second attempt of a powerlifting meet, what will cause excessive cumulative fatigue

As stated in the previous section, the intensity of the protocol is of paramount importance to achieve PAPE. This, combined with specifity of training velocity[135], suggests that to improve performance in powerlifting, eccentric supramaximal protocols[6,41] could be useful. However, using supramaximal protocols in powerlifting implies a high risk due to technique complexity, what raises injury risk[48]. Also, even if eccentric contractions do not imply an energetic waste[148], they do imply higher degrees of muscle damage[149] and this augmented discomfort alters movement pattern[150], what in a complex movement can cause technical breakdown and missing the lift attempt in competition.

In this context, isometric contractions could be helpful. It is known that sustained isometric contractions are energetically less demanding than shortening contractions or brief isometric contractions[151]. Nevertheless, Skurvydas et al. (2019)[5] showed that participants performed worse 10 minutes after a 5s sustained isometric contraction (3.4% of improvement respect to pre-conditioning) than after performing 15 maximal isometric contractions of 1 second with 1 second rest in between (8.3% of improvement respect to pre-conditioning) in maximal voluntary contraction test. Oddly enough, 5s and 10s sustained isometric contractions improved electrically induced twitch torque more than 15 maximal isometric contractions of 1 second with 1 second of rest in between. This discrepancy in performance in those two different tests suggests that sustained isometric contractions produce higher degrees of neural fatigue[133], even if there is less peripheral cellular fatigue[151,152]. Previous studies confirm the utility of isometric protocols in low-loaded exercises[88,153,154], but the question whether isometric PAPE protocols are useful for heavy lifting remains unanswered.

5.4.3 Isometric PAPE and heavy lifting

If isometric contractions are energetically less demanding than shortening contractions (i.e., a hypothetic isometric PAPE protocol should be energetically less demanding than a traditional high intensity dynamic PAPE protocol) and considering that the sticking region is the weakest point of a lift, performing an isometric PAPE protocol in the sticking region is interesting. In this approach, researchers would be trying to acutely improve performance of the weakest point of the lift. Nevertheless, there is something important to consider, the muscle length. It has been mentioned earlier in "*1.2.2.2 Sticking Point or Sticking Region?*" that the sticking region seems to be the point where a clear mechanical disadvantage occurs. This disadvantage can be due to the ratio between internal and external moment arms or due to excessive muscle length. Muscles are formed by sarcomeres, and these sarcomeres have their length-force relationship, meaning that they have an optimum length where they can apply force[155] . When a sarcomere (and by extension a muscle) is too elongated (or too shortened) its capacity to apply active force decreases[102,148]. Thus, whenever the sticking region of an individual is due to excessive elongation of the involved muscle, performing isometric contractions there could not be helpful, but experimental data is lacking. For this reason, in our study[2] bench press grip width was set at 1.4 times biacromial distance, to ensure that the pectoralis major nor the triceps brachii were not excessively elongated.

In that study[2] we compared the effects of an isometric (15 maximal isometric contractions of 1 second with 1 second of rest in between -15 MVIC-) PAPE protocol with a traditional dynamic protocol (1 repetition with 93% 1RM) on mean propulsive velocity and sticking region kinematics of a high loaded (85% 1RM) lift. Mean propulsive velocity did not show significant improvements but sticking region kinematics did. The isometric protocol improved velocity in the pre-sticking region (prior to the initiation of the sticking region) ($p < 0.001$; ES = 0.67, moderate effect; 95% CI [0.07, 0.02]), the 1st maximum velocity peak ($p = 0.005$; ES = 0.71, moderate effect; 95% CI [0.02, 0.093]) and the minimum velocity peak ($p = 0.025$; ES = 0.38, small effect; 95% CI [0.006, 0.072]).

These results could seem of trivial importance, but nothing is further from reality. For experienced lifters, a small change in mean propulsive velocity can suppose the difference between succeeding a lift or failing it (what was confirmed by the smallest meaningful difference calculation carried out in our study´s statistical analyses). Changes in the velocity-time profile of the lift and the sticking region kinematics (i.e., less velocity loss from maximum to minimum velocity points) are due to the greater impulse that the lifter has achieved prior to the sticking region. This augmented capacity to apply force are presumably due to acute strength adaptations by the isometric PAPE protocol, because as stated by Lum & Barbosa (2019)[4], isometric strength training enhances force from the adopted joint angles (in our study[2] the middle of the sticking region) until 20-50º away. This improvement of the first part of the lift (pre-sticking region) can provide the lifter with enough impulse to avoid excessive velocity loss from $V_{max\ peak}$ to $V_{min\ peak}$, furthering participant from failure.

Until this point, it seems that isometric PAPE protocols applied in the Sticking Region are useful to enhance slightly performance (reducing reported RPEs), but not enough to allow lifting more weight. Shortly, findings up to this point suggest that this protocol is helpful to raise success probability in a heavy lift, but it does not improve maximal strength. Exerted active force is a result of the number of cross bridges formed in the high force state[156], and if all motor units are recruited during a maximal strength task[128,141], presumably the maximum quantity of cross bridges are being formed. Thus, it should not be possible to improve the quantity of formed cross bridges without creating new sarcomeres, resulting in an impossibility to improve maximal strength acutely.

What can be done is improving RFD per cross bridge. PAP and PAPE protocols improve RFD due to myosin light chain phosphorylation, what improves myosin´s mobility and gets myosin heads closer to actin binding sites[63,157]. The role of PAP or PAPE in strength sports might be improving performance in submaximal loaded tasks, such as performing sets until volitional failure with 60-80% 1RM. As PAP or PAPE are already commonly used for sprinting[107], jumping[115] or throwing[41], it seems reasonable to think that it will be effective in submaximally loaded strength tasks. Following this line of reasoning, Krzysztofik et al. (2020)[50] and Alves et al. (2019)[49] found conflicting results. Krzysztofik et al. (2020)[50] found no statistically significant differences in the number of performed repetitions, but they found an increase in time under tension for the PAPE group. Contrary to this, Alves et al. (2019)[49] found differences in the performed number of repetitions in the first and second set. The PAPE group performed more repetitions ($p < 0.05$) (PAPE 11.5 ± 3.1 and 6.5 ± 1.9, in the first and second sets respectively) than control group (10.4 ± 2.7, 5.5 ± 1.8, in the first and second sets respectively). One key difference is the used load. While Krzysztofik et al. (2020)[50] used 60% 1RM, Alves et al. (2019)[49] used 75% 1RM. This could suggest that when using excessively light loads, fatigue could underpin results[26,130,141].

Following Alves et al. (2019)[49] results, we conducted a study using only one set until volitional failure with a higher intensity (80% 1RM) in the bench press, where we compared a control group (no PAPE protocol) and a PAPE group (the same warm-up than in control group, but with 1 set of 1 repetition at 93% 1RM prior to the task to failure). Our results supported those by Alves et al. (2019)[49], but also those by, Krzysztofik et al. (2020)[50]. On one hand, participants in the PAPE group performed more repetitions (10.83 ± 2.5 repetitions) than in CON condition (9.76 ± 1.72 repetitions) ($p=0.008$; ES=0.5, small effect). On the other hand, mean propulsive velocity of the last repetition prior to the concentric volitional failure was lower in the PAPE condition (0.16 ± 0.06 $m \cdot s^{-1}$) than in the CON condition (0.2 ± 0.09 $m \cdot s^{-1}$) ($p=0.02$; ES=0.52, small effect), what increases time under tension as in Krzysztofik et al. (2020)[50].

Although this improved performance in submaximal load tasks is not directly relevant for strength competitors, who need for maximal strength improvements, it could be indirectly relevant. As muscle mass is the key determinant of strength performance in advanced lifters[58], improving the hypertrophic stimulus (i.e., improved mechanical tension) received per unit of training bout (i.e., a training set) could be interesting in the long term. To be stronger, hypertrophy is needed at myofibrillar protein level[52], to impulse new sarcomere creation, even though any resistance training programme impulses protein creation also at intracellular level (e.g., ribosome biogenesis[158]) or extracellular level[159]. Depending on trained muscle length or contraction regime, sarcomeres will be added in parallel or in series[102,160], shifting force-length relationship upwards[102] or leftwards[101].

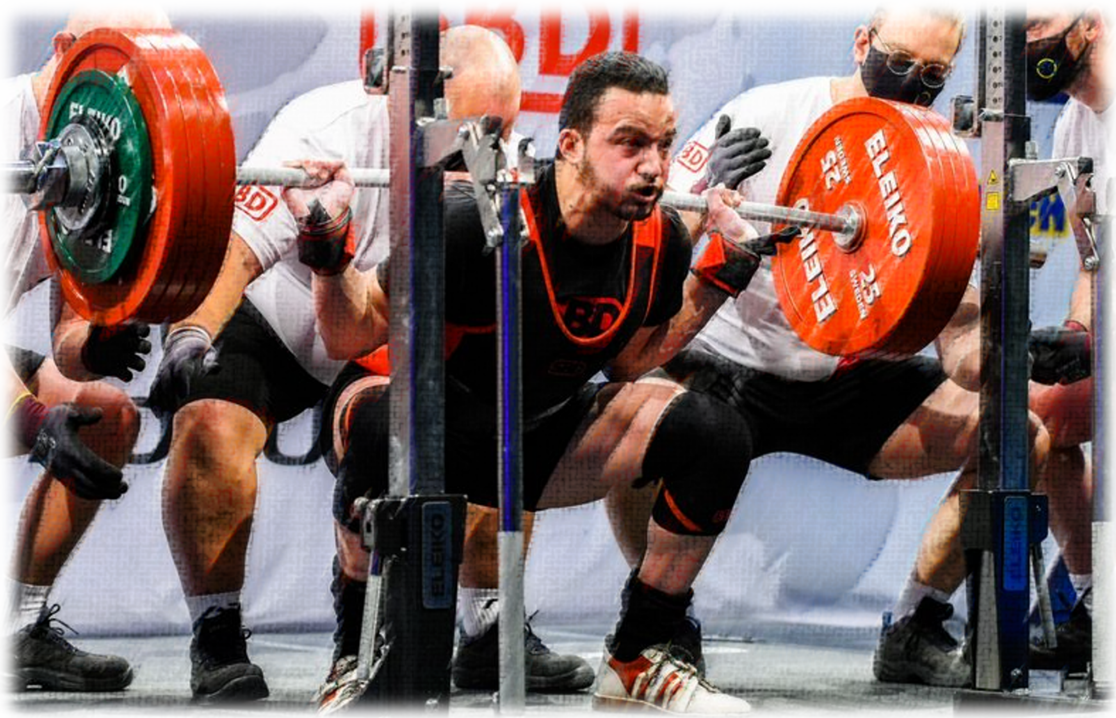
In any case, the interesting aspect of using PAPE for muscle hypertrophy training is based on the augmentation of performed work. If PAPE improves performed number of repetitions until failure, volume load per session (sets x repetitions x kilogram)[136] would improve, and so could muscle hypertrophy. Following this line of reasoning, it could also be assumed that hypothetic muscle hypertrophy benefits could be due to both, improved mechanical tension[22,56] of the last repetition and to higher performed repetitions[136]. In our study[3] performing a traditional PAPE protocol prior to volitional failure made participants more fatigue resistant, achieving more repetitions (9.76 ± 1.72 repetitions the control group, *vs.* 10.83 ± 2.5 repetitions in the PAPE group). This performance improvements in a task to volitional failure in the bench press could be related to an improved capacity to perform slower repetitions, as the PAPE group performed slower the last repetition (0.2 ± 0.09 $m \cdot s^{-1}$ in the control group *vs.* 0.16 ± 0.06 $m \cdot s^{-1}$ in the PAPE group). In consequence, the velocity loss was greater from the first to the last repetition and previous studies support the notion that with a greater velocity loss, muscle hypertrophy gains can be greater [134]. This means that the performed extra repetition may be effective when aiming to produce muscle hypertrophy, what means that the efficacy of every set would be higher (i.e., the achieved hypertrophy for every set would be higher).

6

LIMITATIONS & FUTURE RESEARCH

Look to what is within: do not allow the intrinsic quality or the worth of any one fact to escape you

Marcus Aurelius – Meditations VI 3



6. LIMITATIONS & FUTURE RESEARCH

6.1 Limitations

Our work faced some limitations:

- Our first original research aimed to measure mean propulsive velocity changes with a device that was not sensitive enough (e.g., real magnitude changes were about 0.001 $m \cdot s^{-1}$ and the used device measures 0.01$m \cdot s^{-1}$ or higher velocities). This difficulted statistical analysis and result interpretation in mean propulsive velocities. Nevertheless, indirect measurements using Kinovea based digitalisation allowed for instantaneous velocity comparisons, what allowed to compare results more precisely.
- Our second original research faced with sample size limitation, making difficult to generalise achieved results. However, obtained sample was formed by trained individuals, what is representative of the competitive population.
- In our second original research we talk about hypothetic applications of PAPE for muscle mass gain, but longitudinal data is needed to firmly confirm that hypothesis.

6.2 Future research

Future work, based on what has been presented above could focus on the following:

- A wide range of available protocols exist already. It would be interesting to test the different time-potentiation profiles of two protocols matched in volume load but with different intensities, to see if the time-potentiation profile is the same in shape but different in time until peak performance.

- Isometric PAPE protocol applied in the middle of the sticking region based on 15 MVIC with 1 second rest in between has proved its efficacy improving lifting efficiency. It would be interesting to test the application of the same protocol in larger muscle lengths, to test whether it causes more fatigue due to acute muscle damage or improves performance.
- As PAPE protocols seem to improve performed work per session, it would be interesting to design a study between 8 – 16 weeks to test if the potential benefit on hypertrophy is real or only hypothetic.
- PAP´s and PAPE´s underlying mechanisms are not mutually exclusive, as PAPE could be a side effect of PAP or an extender PAP. The role of temperature seems interesting but remains to be proven as a mechanism for PAPE. It would be worth researching the real role of temperature in any PAPE protocol.

7

CONCLUSIONS

Forget your lust for the rich man´s gold

All that you need is in your soul

And you can do this, oh babe, if you try

All that I want for you my son, is to be satisfied

And be a simple kind of man

Be something you love and understand

Lynyrd Skynyrd – Simple man

7. CONCLUSIONS

7.1 Conclusions

After analysing a wide range of information about PAPE and its possible protocols, it seems that to produce an effective potentiation effect trainers and coaches should look for a correct balance between stimulus and fatigue. Until relatively recent times, PAP and PAPE protocols were submaximally loaded dynamic protocols. When the importance of the balance between stimulus and fatigue was understood, supramaximal[6] and isometric[88] protocols were tested. As relationship between potentiation and fatigue is of paramount importance[65] to achieve favourable results, nothing seems to suggest that supramaximal, maximal, or plyometric protocols cannot be used. In this regard, coaches should account for generated fatigue to suggest rest intervals. For example, when performing supramaximal eccentric contractions, muscle damage[149] is higher than during submaximal dynamic contractions and it suggests that even if eccentric contractions are energetically less demanding[148,161], rest intervals should be long.

One of the commonly overlooked variables when prescribing rest intervals between conditioning activity and the re-test task is movement complexity. Studies are commonly carried out in smith machines to ensure movement standardisation and participant safety, but advanced lifter´s movements are rarely linear[162] . Movement out of smith machines are more complex, as they need for stabilisation as well as force output, making the movement more difficult, and the more complex the movement, the more fatigue is generated[163]. Thus, technical complexity should be taken into consideration when extrapolating results from a study to field conditions.

In this regard, isometric contractions could be helpful. There is no technical complexity, as they do not require movement. Isometric contractions are energetically less demanding than shortening (concentric) contractions[131], but more demanding than eccentric contractions[155,161] . Thus, considering that isometric contractions are energetically more demanding than eccentric contractions, but technically simpler, rest intervals could be relatively similar for both type of protocols (i.e., 5-7 min for stronger individuals and ≥8 min for weaker individuals[30]).

Another scenario where isometric PAPE protocols are useful is when coaches seek for potentiation in heavy, near maximal loaded lifts. As we have demonstrated in our study[2], mean propulsive velocity may not improve significantly, but peak velocities of the sticking region do, easing the lift. This improvement in sticking region´s key points (i.e., V_{max1} and V_{min}) is achieved with an isometric contraction-based PAPE protocol performed in the deceleration zone[164] of the sticking region.

The third and last aim of this thesis was testing the impact of a PAPE protocol in training volume. In this case, the proposed PAPE protocol was a traditional[1] dynamic protocol, as tasks to volitional failure are carried out with submaximal load. Evidence in this field is scarce and contradictory, but our results supported those by Alves et al. (2019)[49], stating that a PAPE protocol can improve resistance training volume. This improvement can be due to psychological reasons[47] or to training velocity specifity reasons[135].

As the coach I am, in commencing this thesis, I aimed to try to better understand the gap between science and practice. This dissertation covers the topic of PAPE in different and often used situations for a strength coach, and therefore, I would like to summarise the conclusions drawn from this work:

- Conclusion 1: Coaches need to start differentiating PAP from PAPE and Sticking Region from Sticking Point
- Conclusion 2: A PAPE protocol is an acute fitness-fatigue model. If volume is high, intensity needs to be low, and vice versa. If used volume and intensity are high, the use of clusters can be helpful.
- Conclusion 3: Strong individuals benefit more from heavy loaded protocols than novice individuals. In addition, stronger individuals need shorter rest intervals (5-7 min) than their weaker counterparts (≥8 min)
- Conclusion 4: Traditional PAPE protocols are not useful when trying to improve heavy lifting. Isometric PAPE protocols are useful in this scenario
- Conclusion 5: Isometric PAPE protocols do not improve maximal strength, but they improve Sticking Region kinematics, slightly easing the lift and furthering the athlete from failure
- Conclusion 6: A traditional high-loaded PAPE protocol can improve resistance training performance to volitional failure. This could improve performed volume per session

7.2 Conclusiones

Después de analizar mucha información sobre PAPE y los posibles protocolos, parece que, para producir una potenciación efectiva, los entrenadores deben buscar un equilibrio correcto entre estímulo y la fatiga. Hasta hace relativamente poco, los protocolos de PAP y PAPE eran protocolos dinámicos con carga submáxima. Cuando se entendió la importancia del equilibrio entre estímulo y fatiga, se estudiaron los protocolos supramáximo[6] e isométrico[88]. Dado que la relación entre la potenciación y la fatiga es de suma importancia[65] para lograr resultados positivos, nada parece sugerir que no se puedan utilizar protocolos supramáximos, máximos o pliométricos. En este sentido, los entrenadores deben tener en cuenta la fatiga generada para pautar intervalos de descanso. Por ejemplo, cuando se realizan contracciones excéntricas supramáximas, el daño muscular[149] es mayor que durante las contracciones dinámicas submáximas y aunque si las contracciones excéntricas son energéticamente menos demandantes [148,161], los intervalos de descanso deberían ser largos.

Una de las variables que comúnmente se pasa por alto cuando se pautan intervalos de descanso entre el ejercicio de potenciación y la tarea de re-test, es la complejidad del movimiento. Los estudios suelen llevarse a cabo en máquinas Smith para garantizar la estandarización del movimiento y la seguridad de los participantes, pero los movimientos de los levantadores avanzados rara vez son lineales [162]. Los movimientos fuera de las máquinas Smith son más complejos, ya que necesitan estabilización además de ejercer fuerza, lo que hace que el movimiento sea más difícil, y cuanto más complejo es el movimiento, más fatiga se genera [163]. Por lo tanto, la complejidad técnica debe tenerse en cuenta al extrapolar los resultados de un estudio a condiciones de campo.

En este sentido, las contracciones isométricas podrían ser útiles. No hay complejidad técnica, ya que no requieren movimiento. Las contracciones isométricas son energéticamente menos exigentes que las contracciones concéntricas[131], pero más exigentes que las excéntricas [155,161]. De este modo, considerando que las contracciones isométricas son energéticamente más exigentes que las contracciones excéntricas, pero técnicamente más simples, los intervalos de descanso podrían ser relativamente similares para ambos tipos de protocolos (es decir, 5-7 min para individuos más fuertes y $\geq$8 min para individuos más débiles[30]).

Otro escenario en el que los protocolos de PAPE isométricos son útiles, es cuando los entrenadores buscan mejorar el rendimiento en levantamientos pesados con carga casi máxima. Como hemos demostrado en nuestro estudio[2], es posible que la velocidad media propulsiva no mejore significativamente, pero sí lo hacen las velocidades máximas de la región de estancamiento, lo que facilita el levantamiento. Esta mejora en los puntos clave de la región de estancamiento (es decir, V_{max1} y V_{min}) se logra con un protocolo de PAPE basado en contracciones isométricas realizadas en la zona de desaceleración[164] de la región de estancamiento.

El tercer y último objetivo de esta tesis fue probar el impacto de un protocolo de PAPE en el volumen de entrenamiento. En este caso, el protocolo de PAPE propuesto era un protocolo dinámico tradicional[1], ya que las series al fallo concéntrico se realizan con carga submáxima. La evidencia en esta área es escasa y contradictoria, pero nuestros resultados respaldaron los de Alves et al. (2019) [49], afirmando que un protocolo de PAPE puede mejorar el volumen de entrenamiento de fuerza. Esta mejora puede deberse a razones psicológicas [47] o a razones de especificidad de la velocidad de entrenamiento [135].

Como entrenador que soy, al comenzar esta tesis, mi objetivo era tratar de comprender mejor la brecha entre la ciencia y la práctica. Esta tesis trata el tema de la PAPE en diferentes (y frecuentes) situaciones para un entrenador de fuerza, y por lo tanto, me gustaría resumir las conclusiones extraídas:

- Conclusión 1: Los entrenadores deben comenzar a diferenciar PAP de PAPE y región de estancamiento de punto de estancamiento
- Conclusión 2: Un protocolo de PAPE es un modelo de fitness-fatiga agudo. Si el volumen es alto, la intensidad debe ser baja y viceversa. Si el volumen y la intensidad usados son altos, el uso de series cluster puede ser útil
- Conclusión 3: Las personas fuertes se benefician más de los protocolos pesados que las personas novatas. Además, los individuos más fuertes necesitan intervalos de descanso más cortos (5-7 min) que sus compañeros más débiles (≥8 min)
- Conclusión 4: Los protocolos de PAPE tradicionales no son útiles cuando se trata de mejorar el rendimiento en levantamientos pesados. Sin embargo, los protocolos PAPE isométricos son útiles en este escenario
- Conclusión 5: Los protocolos de PAPE isométricos no mejoran la fuerza máxima, pero mejoran la cinemática de la región de estancamiento, facilitando ligeramente el levantamiento y evitando que el atleta falle
- Conclusión 6: Un protocolo PAPE tradicional de alta intensidad puede mejorar el rendimiento de una serie llevada al fallo concéntrico. Esto podría mejorar el volumen realizado por sesión

8

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Let no one delay in the study of philosophy while he is young, and when he is old, let him not become weary of the study; for no man can ever find the time unsuitable or too late to study the health of his soul

Epicurus – Letter to Menoeceus

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9

ADDENDUMS

You go talk to kindergarten or first-grade kids, you find a class full of science enthusiasts. They ask deep questions. They ask "What is a dream? Why do we have toes? Why is the moon round? Why is grass green?"

These are profound, important questions. They just bubble right out of them.

You go talk to 12th graders and there's none of that. They've become incurious. Something terrible has happened between kindergarten and 12th grade.

Carl Sagan – Mary Hynes speaking with Carl Sagan in a TV interview

Study 1

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Section III – Sports Training

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Post-Activation Potentiation in Strength Training: A Systematic Review of the Scientific Literature

by
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This review aimed to determine the ideal combination of post activation potentiation (PAP) strategies for an improved strength performance. After analysing 202 articles, 15 studies met the inclusion criteria. The findings of this review suggest that a potentiation effect exists as long as a minimum intensity and enough rest are provided. Although intensities of 65% 1RM are sufficient to elicit a potentiation effect, higher effects can be achieved with 85 - 90% 1RM intensities. Similarly, we found that experienced athletes will benefit more from a higher volume bout (1-3 sets), as long as 7-8 minutes of rest are allowed to avoid fatigue.

Key words: *PAP, complex training, performance, resistance training, strength training.*

Introduction

During the last few years post-activation potentiation (PAP) has been used to acutely improve power output and muscular function (Maloney et al., 2014). PAP is commonly used during the warm-up through complex training, which refers to a training method where heavy resistance exercises are used prior to a biomechanically similar ballistic movement (Poulos et al., 2018).

PAP acts through skeletal muscle contractile history, where the muscle is pre-activated with a higher load using a conditioning activity before performing a training session or a competition. Two mechanisms have been suggested: (i) the phosphorylation of myosin regulatory light chains and (ii) improved α-motoneuron excitability (Gołas et al., 2016). Additionally, according to the vector theory (Morin et al., 2010), biomechanical similarities between the conditioning and the effective activity (the competition, training bout or test) play a crucial role in potentiation. Four main variables are thought to act over the conditioning activity: (i) intensity to activate the working mechanisms (Gołas et al., 2016), (ii) volume, which is inversely proportional to intensity, (iii) resting time, which is directly conditioned by intensity and volume (Kilduff et al., 2008), and (iv) movement similarity (Dello Iacono et al., 2018).

To date, very different protocols have been used trying to achieve optimal potentiation with opposing results (Dello Iacono et al., 2018; Gołas et al., 2017; Kobal et al., 2019). Thus, the aim of this review was to compare different protocols and to clarify the importance of the aforementioned variables on the conditioning activity. We hypothesized that the volume load would be the main conditioning factor to achieve an optimal potentiation, followed by intensity.

Methods

Experimental Approach to the Problem

A literature search was conducted on October 23, 2020. The following databases were searched: PubMed and Scopus. The previously named databases were searched from inception to October 2020, with language limitations: only peer reviewed articles in English were selected.

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Citations from scientific conferences were excluded.

Literature Search

In the database, the title and abstracts were searched. The following MeSH terms and key words, combined with the Boolean operators (AND, OR), were used: "athletic performance", "resistance training", "post activation potentiation", "PPA", "PAP", "post-activation potentiation", "potentiation post activation", "potentiation post-activation", "performance", "strength performance", "strength training", "strength" and "powerlifting". No additional filters or search limitations were used.

Inclusion Criteria

Studies were eligible for further analysis if the following inclusion criteria were met; a) subjects´ age ranged between 18-30 years; b) studies analysed experienced lifters; c) post-activation potentiation was studied in sports with high requirements of the rate of force development; d) the potentiation protocol was conducted with barbell exercises; e) pre- and post-evaluation was done with a resistance exercise, vertical jump or similar (i.e. squat jump, counter movement jump or drop jump). In the studies where volume was not directly reported, it was calculated as follows: volume = sets x repetitions x kilograms.

Quality assessment

Oxford's level of evidence (OCEBM Levels of Evidence Working Group, 2011) and the Physiotherapy Evidence Database (PEDro) scale (Maher et al., 2003; de Morton, 2009) were used in order to assess the methodological quality of the studies included in the review. Oxford's level of evidence ranges from 1a to 5, with 1a being systematic reviews of high-quality randomized controlled trials (RCT) and 5 being expert opinions. The PEDro scale consists of 11 different items related to the scientific rigor. Given that assessors are rarely blinded and that blinding participants is almost impossible, items 5-7 (which are specific to blinding) were removed from the scale (Baz-Valle et al., 2018). With the removal of these items, the maximum result on the modified PEDro scale was 7 (the first item is not included in the final score) and the lowest, 0. Zero points are awarded to a study that fails to satisfy any of the included items and 7 points to a study that satisfies all the included items.

Results

Studies Selected

The search strategy yielded 202 total citations as presented in Figure 1. From those 202 articles, 17 met the inclusion criteria. Excluded studies had at least one of the following characteristics: the potentiation protocol included strategies different from resistance training (e.g. electrostimulation or vibration), participants were not experienced lifters (had less than 2 years of resistance training experience or less than 2 x bodyweight squat 1-RM) or the evaluation protocol was done with sprinting bouts (Table 1).

Level of Evidence and Quality of the Studies

Ten of the seventeen included studies had a level of evidence 1b (good quality randomized control trials). The 7 remaining studies had a level of evidence of 2b (individual cohort studies). Also, the mean score in the PEDro scale was 6.47 ± 0.87, with values ranging from 5 to 7 (Table 1).

Characteristics of the Participants

Participants were characterized as experienced or well-trained athletes due to their training experience or their one repetition maximum (the maximum amount of weight that a person is able to lift for one repetition). A summary of participants´ characteristics is presented in Table 2. The total number of participants was 279 (253 men, 6 women and 20 unknown).

Studies matching volume load

Five of the included 17 studies matched the volume load in the protocols used. From these five studies, three compared different intensity protocols (Dello Iacono et al., 2019; Lowery et al., 2012; Mina et al., 2019) and two the optimal rest interval (do Carmo et al., 2018; Kilduff et al., 2008).

Mina et al. (2019) performed a study comparing free weight back squats and variable resistance back squats (elastic bands were used to generate the 35% of the total load at the upper part of the squat). Under the free weight condition, no significant changes were found in jump height, peak power or a normalized (to body weight) rate of force development (RFD) compared to pre-intervention performance. On the other hand, under the variable resistance condition, statistically significant increases ($p < 0.05$) in CMJ height were observed at 30 s (5.9 ± 1.2%), 4 min (5.6 ± 1.8%), 8 min (6.5 ± 2.6%) and 12 min (5.3 ± 2.5%) compared to pre-intervention. In addition, statistically significant increases ($p < 0.05$) were evident in peak power at 30 s (4.7 ± 1.2%), 4 min (5.9 ± 1.3%), 8 min (4.4 ± 1.7%) and 12 min (4.8 ± 1.7%) time points. These changes in CMJ height and peak power were also significantly different from the free weight condition group ($p < 0.05$).

Dello Iacono et al. (2019) compared the effect of two protocols using the individualized optimal power load with traditional and cluster-set configuration in a randomized cross-over design. Although both protocols increased jump height 4 and 8 min post-intervention, the cluster set configuration reached significantly better results by 1.33 cm (95% CI, 1.02 to 1.65 cm) and 1.64 cm (95% CI, 1.41 to 1.88 cm), respectively. Additionally, cluster set configuration was able to maintain 10% higher power output (95% CI, 8 to 12%) relative to their relative mean propulsive power.

Lowery et al. (2012) studied the effects of three different loads (light, 56% 1RM; medium, 70% 1RM; and heavy, 93% 1RM) on vertical jump height. Vertical jumps after the light load protocol did not reach statistically significant differences. Moderate and high load protocols decreased vertical jump performance right after the conditioning activity ($p < 0.05$; $ES_{medium\ loaded} = -2.45$, large; $ES_{heavy\ loaded} = -2.87$, large). Additionally, a medium loaded protocol reached a significant performance increase at 4 min in the post activation training protocol ($p < 0.05$; ES = 1.46, large) and a high loaded protocol reached statistically significant improvements at both 4 and 8 min post protocol ($p < 0.05$; $ES_{4min} = 1.34$, large; $ES_{8min} = 1.48$, large).

Kilduff et al. (2008) attempted to set the optimal recovery time for a complex training session. Participants performed 3 sets of 3 repetitions at 87% 1RM back squats before an explosive activity. They reported a statistically significant ($p < 0.05$) decrease at 15 s post conditioning activity and a statistically significant ($p < 0.05$) increase at 8 min post conditioning activity for power output and for jump height. A statistically significant ($p < 0.05$) increase in the RFD 8 min post conditioning activity was also reported. Additionally, Do Carmo et al. (2018) suggested that self-selected rest intervals were better than a fixed rest interval in order to dissipate the fatigue created by the conditioning activity. They conducted a study and no significant changes were observed after the conditioning activity in the fixed rest interval group (38.0 ± 5 cm vs. 37.7 ± 5.1 cm; $p = 0.4$; ES = 0.04) nor in the self-selected rest interval group from pre- to post-test (38.2 ± 4.6 cm vs. 40.5 ± 4.4 cm).

Studies not matching volume load

The remaining twelve of the included 17 studies did not match the volume load in the protocols used. Four of these studies (Comyns et al., 2007; Gilbert and Lees, 2005; Krzysztofik et al., 2020b, 2020c) support the relationship between a higher volume load and potentiation stimuli. Of the remaining 8 studies, one analysed the neuromuscular function (Thomas et al., 2017), compared PAP in exercised and contralateral legs (Andrews et al., 2016), compared the relationship between PAP and time under tension (Krzysztofik et al., 2020a) and another studied the effects of plyometric PAP in bench press throw (Krzysztofik and Wilk, 2020). The remaining 4 reported contradictory results (Golas et al., 2017; Kobal et al., 2019; Poulos et al., 2018; Reardon et al., 2014).

Four studies (Comyns et al., 2007; Gilbert and Lees, 2005; Krzysztofik et al., 2020b, 2020c) support the notion of higher volume loads as better potentiation stimuli. These three studies compared different intensities and volumes ranging from 65% 1 RM to 130% 1 RM. Gilbert and Lees (2005) found statistically significant increases in the isometric RFD in the 1RM group at 15 min ($p = 0.021$) and 20 min ($p = 0.006$), with a peak increase of 11.8%. In the optimal power load group, a statistically significant increase ($p = 0.038$) in the isometric RFD was found at 2 min, with a peak increase of 6.7%. Comyns et al. (2007) found that contact time showed a statistically significant reduction ($p < 0.05$) and vertical leg spring stiffness indicated a significant increase ($p < 0.05$) for the heavy loaded protocol (93% 1RM). However, there were significantly ($p < 0.01$) shorter flight times for all the protocols. Krzysztofik et al. (2020b) compared the differences between a classic PAP protocol (2 sets of 2 repetitions of the concentric bench press at 90% 1-RM) and eccentric protocols (2 sets of 2 repetitions of either only eccentric 90% 1-RM, only eccentric 110% 1-RM or only eccentric 130% 1-RM bench press). The study reported better potentiation results with eccentric only protocols, achieving greater peak velocity ($\eta^2 = 0.441$; $p = 0.019$) and greater mean velocity ($\eta^2 = 0.011$; $p = 0.041$) after the 110% 1-RM eccentric only protocol and greater peak velocity after the 130% 1-RM eccentric only protocol ($\eta^2 = 0.323$; $p = 0.037$). In another study by Krzysztofik et al. (2020c) with the same eccentric protocols, the bench press throw with a load of 30% 1-RM improved peak power by 10.5 ± 6.0% (effect size = 0.34) and by 9.9 ± 8.1% (effect size = 0.33) for the 110 and 130% 1-RM conditions, respectively. Peak velocity increased by 5.9 ± 5.5% (effect size = 0.4) and by 6.1 ± 6.1% (effect size 0.43) for the 100 and 130% 1-RM protocols, respectively. Since sets and repetitions remained the same through protocols, the differences in volume load were a result of the different intensities.

Four studies (Golas et al., 2017; Kobal et al., 2019; Poulos et al., 2018; Reardon et al., 2014) showed conflicting results. In the study by Poulos et al. (2018) both protocols (10 sets of 3 or 5 repetitions with 87% 1RM *vs*. 65% 1RM respectively) enhanced jump height (65% 1RM: +3.3 ± 2.2% [CI: 1.0 to 5.6]; 87% 1RM +2.6% ± 1.9% [CI: 0.7 to 4.5]) after 10 sets. Nevertheless, there was a larger chance of jump height improvement when CMJs were performed across the 10 sets of squats in the protocol of 87% 1RM. Golas et al. (2017) compared five different protocols and they observed statistically significant ($p = 0.01$) differences in the RFD and the rate of power development (RPD) ($p = 0.02$) in the medium volume load group (80% 1RM) compared to the other conditions. Additionally, Kobal et al. (2019) found that a lower volume load with a higher intensity (100% 1RM) protocol induced similar results to a higher volume load and lighter load protocol (93% 1RM and 87% 1RM). Reardon et al. (2014) found no performance improvement in any of their protocols (3 sets of either 10 or 3 repetitions with 75% 1RM *vs*. 90% 1RM).

Thomas et al. (2017) analysed neuromuscular function using EMG during a PAP protocol. Countermovement jump height increased significantly ($p = 0.008$) from pre- to post-potentiation (from 41.0 ± 4.3 cm to 44.7 ± 4.1 cm). Neuromuscular function was measured before the first CMJ and after the last CMJ. A small and statistically non-significant decrease in the maximum voluntary contraction (MVC) ($p = 0.142$) and in voluntary activation ($p = 0.06$) was observed, but potentiated twitch force was significantly ($p < 0.001$) reduced after strength training (235 ± 65 N to 185 ± 51 N) in comparison to the control group.

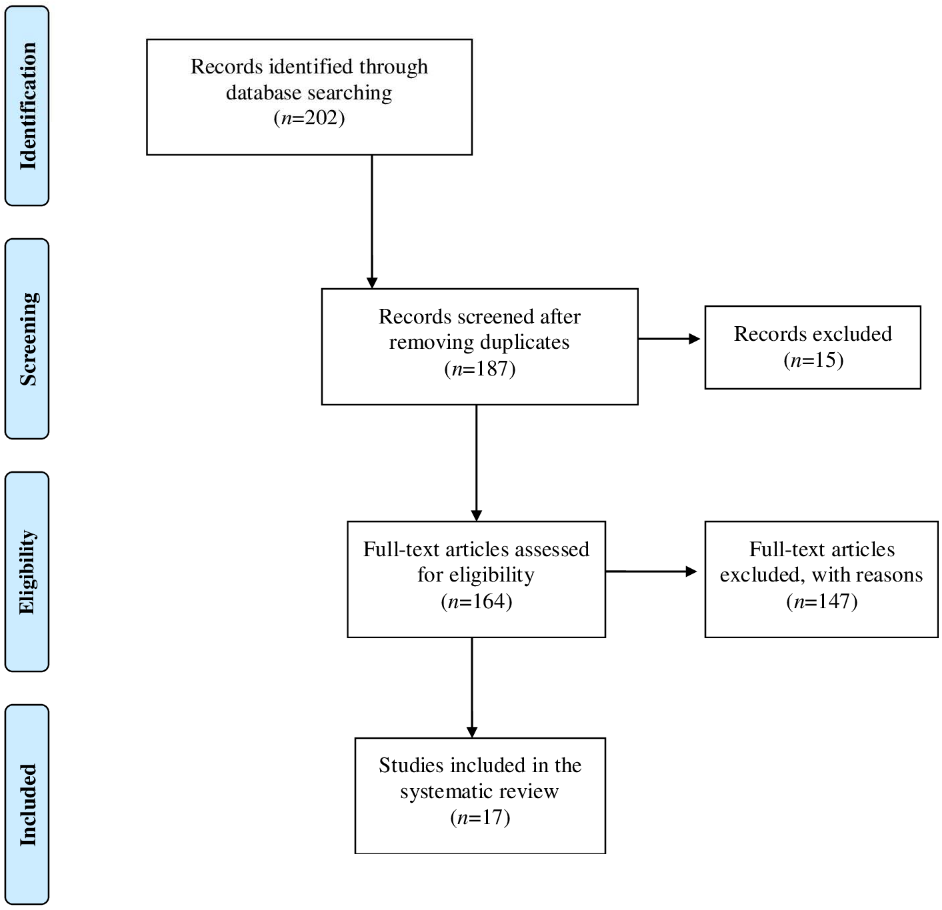
Andrews et al. (2016) studied the effect of unilateral squats potentiation in the exercised leg and in the contralateral leg using a low fatigue protocol. The results showed no statistically significant differences at 1, 5 and 10 min in comparison to pre-test values for the drop jump contact time or the drop jump reactive strength index. Regarding the CMJ, a condition x time interaction indicated that the exercised leg exhibited significant but small to trivial magnitude jump height increases of 4.0% ($p = 0.02$; d = 0.36), 0.9% ($p = 0.06$; d = 0.08) and 1.6% ($p = 0.04$; d = 0.15) at 1, 5 and 10min post-intervention, respectively. The contralateral leg, on the other hand, had trivial CMJ deficits post intervention: 1.3% ($p = 0.23$; d = 0.12), 0.9% ($p = 0.09$; d = 0.10) and 1.7% ($p = 0.03$; d = 0.19) at 1, 5 and 10min post-intervention, respectively.

Krzysztofik and Wilk (2020) showed that 3 sets of 5 repetitions of plyometric push ups with 1 min rest intervals improved bench press peak velocity ($p < 0.01$) and mean velocity ($p < 0.01$) compared to a control group. In addition, Krzysztofik et al. (2020a) also found that a PAP protocol consisting of 3 sets of 3 repetitions at 85% 1-RM achieved higher training volume based on time under tension at the end of the training session ($p < 0.01$) when compared to a control group, despite completing the same number of repetitions.

Discussion

The main finding of this systematic review is that the volume load plays an important role in performance enhancement after a conditioning activity. Four studies firmly support that the volume load is the main conditioning factor to achieve an optimal potentiation effect (Comyns et al., 2007; Gilbert and Lees, 2005; Krzysztofik et al., 2020b, 2020c), while four showed contradictory results (Gołas et al., 2017; Kobal et al., 2019; Poulos et al., 2018; Reardon et al., 2014). This systematic review also shows that when the total volume is low, intensity seems to be decisive (Andrews et al., 2016; Poulos et al., 2018).

PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Figure 1

Flow chart of search strategy and selection of articles.

Table 1

Physiotherapy Evidence Database (PEDro) ratings and Oxford evidence levels of the included studies.

Study	1	2	3	4	5	6	7	8	**Total**	**Evidence level**
Andrews et al. (2016)	Yes	1	1	1	1	1	1	1	7	1b
Comyns et al. (2007)	Yes	1	1	1	1	1	1	1	7	1b
Dello Iacono et al. (2019)	Yes	1	1	1	1	1	1	1	7	1b
Do Carmo et al. (2018)	Yes	1	1	1	1	1	1	1	7	2b
Gilbert & Lees (2007)	Yes	1	1	1	1	1	1	1	7	1b
Golas et al. (2017)	Yes	1	1	1	1	1	1	1	5	2b
Kilduff et al. (2008)	Yes	0	0	1	1	1	1	1	5	2b
Kobal et al. (2019)	Yes	0	0	1	1	1	1	1	5	2b
Krzysztofik et al. (2020a)	Yes	1	1	1	1	1	1	1	7	1b
Krzysztofik et al. (2020b)	Yes	1	1	1	1	1	1	1	7	1b
Krzysztofik et al. (2020c)	Yes	1	1	1	1	1	1	1	7	1b
Krzysztofik and Wilk (2020)	Yes	1	1	1	1	1	1	1	7	1b
Lowery et al. (2012)	Yes	1	1	1	1	1	1	1	7	2b
Mina et al. (2019)	Yes	1	1	1	0	1	1	1	6	1b
Poulos et al. (2018)	Yes	1	1	1	1	1	1	1	7	1b
Reardon et al. (2014)	Yes	1	1	1	1	1	1	1	7	2b
Thomas et al. (2015)	Yes	1	0	0	1	1	1	1	5	2b

Items in the PEDro scale: 1 = eligibility criteria were specified; 2 = subjects were randomly allocated to groups; 3 = allocation was concealed; 4 = the groups were similar at baseline regarding the most important prognostic indicators; 5 = measures of 1 key outcome were obtained from 85% of subjects initially allocated to groups; 6 = all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least 1 key outcome were analysed by "intention to treat"; 7 = the results of between-group statistical comparisons are reported for at least 1 key outcome; 8= the study provides both point measures and measures of variability for at least 1 key outcome

Table 2

Included studies

Study	Number (M/F)	Age (years)	RT experience (years)	Main Outcome
Andrews et al. (2016)	14 (8/6)	M 21.3 ± 1.8 / F 21.2 ± 0.4	≥ 2	Unilateral PAP and fatigue
Comyns et al. (2007)	12 (12/0)	23.3 ± 2.5	1RM ≥ 2x bodyweight	Optimal resistive load and PAP
Dello Iacono et al. (2019)	26 (26/0)	23.2 ± 5.1	≥ 2	Traditional sets PAP vs cluster sets PAP
Do Carmo et al. (2018)	12 (12/0)	25.4 ± 3.6	≥ 3	PAP rest interval
Gilbert and Lees (2007)	15 (15/0)	24.3 ±3.3	unknown	Changes in force development
Golas et al. (2017)	16 (16/0)	18-35	≥ 5	Used PAP load magnitude
Kilduff et al. (2008)	20 (Unknown)	25.4 ± 4.8	3.1 ± 1.6	Recovery time and PAP
Kobal et al. (2019)	18 (18/0)	25.42 ± 3.58	3	Different volume and PAP
Krzysztofik et al. (2020a)	12 (12/0)	25.2 ± 2.1	3	PAPE and training volume
Krzysztofik et al. (2020b)	32 (32/0)	28.4 ± 4.5	3	Eccentric and concentric PAP
Krzysztofik et al. (2020c)	13 (13/0)	25.7 ±1.9	6.5 ± 2.2	Eccentric PAP
Krzysztofik and Wilk (2020)	24 (24/0)	24.5 ± 2.6	6.3 ± 2.5	Plyometric PAP protocol
Lowery et al. (2012)	13 (13/0)	21 ± 3	3	PAP stimuli and recovery time
Mina et al. (2019)	15 (15/0)	21.7 ± 1.1	≥ 5	PAP: free weight vs variable resistance
Poulos et al. (2018)	15 (15/0)	24.3 ± 2.6	≥ 2	Back Squat intensity and PAP
Reardon (2014)	11 (11/0)	25.18 ± 3.60	1RM ≥ 2x bodyweight	Muscle architecture and PAP
Thomas et al. (2015)	11 (11/0)	23 ± 4	≥ 2	PAP and neuromuscular function

PAP = post activation potentiation; M = male; F = female; RT = resistance training

Recruitment of type II fibers is needed to achieve potentiation, which is the result of combining volume and intensity (Bawa et al., 2014; Bompa and Haff, 2009; Henneman et al., 1974; Maloney et al., 2014). As stated by Schoenfeld (2010), in order to recruit high order motor units, light loads are not as effective as heavy loads. In the four studies (Comyns et al., 2007; Gilbert and Lees, 2005; Krzysztofik et al., 2020b, 2020c) firmly supporting our hypothesis, high intensities were used (up to 130% 1 RM) to achieve higher volume loads. However, potentiation can be achieved using lower volume loads as well (Gołas et al., 2017; Kobal et al., 2019). Gołas et al. (2017) and Kobal et al. (2019) performed between 3 and 5 sets with different loads ranging from 60% 1 RM to 100% 1-RM with a fixed rest interval. Considering that fatigue is especially evident when training is performed close to 1-RM or to failure (Dankel et al., 2017; Zajac et al., 2015), the better potentiation achieved in these studies with lower volume loads may rely on the rest-time between the conditioning activity and the re-test. Although according to Do Carmo et al. (2018) a self-selected rest may be sufficient to improve performance, other studies suggest that potentiation values peak after 8 min or longer resting periods (Gilbert and Lees, 2005; Kilduff et al., 2008).

The second finding is that a minimum effective intensity is needed to achieve potentiation. However, intensity should be understood as the amount of repetitions in reserve and not as the percentage of 1-RM. In order to achieve potentiation, we can either use light loads with high volumes or high intensities with low volumes (Bompa and Haff, 2009). Thus, when leaving at least 2 repetitions in reserve, performing multiple sets leads to potentiation without accumulating excessive fatigue (Andrews et al., 2016; Poulos et al., 2018). However, although lowering intensity during the conditioning activity may lead to lesser fatigue (Mina et al., 2019), leaving too many repetitions in reserve may not provide enough stimuli to elicit potentiation (Helms et al., 2016; Reardon et al., 2014). On the other hand, leaving too few repetitions in reserve (between 0 and 1) may lead to excessive fatigue and impaired performance after the conditioning activity (Helms et al., 2016; Reardon et al., 2014). In this way, the higher the intensity, the longer the rest interval the athlete needs to dissipate fatigue (do Carmo et al., 2018; Gilbert and Lees, 2005).

We also found different time-potentiation profiles for high- and medium-load protocols. In the study by Lowery et al. (2012), heavy and medium protocols peaked at the same time point, but potentiation achieved with the heavy loaded protocol was maintained for a longer time. These findings are in line with those of Gilber and Lees (2005), who reported different time-potentiation profiles; while the optimal power load group peaked earlier, the heavy loaded protocol group peaked later but with a higher potentiation effect (6.7% vs. 11.8%, respectively). These findings are in line with those by Krzysztofik and Wilk (2020) who observed the greater increase in peak velocity and mean velocity of the bench press in the first set after the plyometric push ups protocol. Thus, the time-potentiation profiles seem to be determined by the intensity of the stimuli and the resting time (fatigue-potentiation relationship). Fatigue in resistance training, as suggested by Zajac et al. (2015), is produced by post-exercise intramuscular perturbations (i.e., decrease in phosphocreatine, glycogen, ATP stores and augmentation of phosphate and hydrogen ions) and modulation of central motor drive during exercise by nociceptive afferent input (III and IV muscle afferents). These changes are especially evident when training sessions are close to 1-RM. During submaximal contractions, the closer to failure, the more motor units are recruited, but also the higher the metabolite accumulation, which contributes to fatigue (Dankel et al., 2017). This may partially explain the differences in the potentiation protocols leaving too many (Andrews et al., 2016) or too little (Reardon et al., 2014) repetitions in reserve during submaximal efforts.

We have to acknowledge several limitations. These include the lack of raw data for a deeper analysis. The main purpose of the review was to summarize the evidence so far and, if possible, to analyse differences in used protocols based on the volume load. While the most recent studies included raw data, the oldest ones did not. This limited our intention to compare the volume load of different protocols as we could not calculate it for 2 of the 13 studies. Another important limitation was related to the heterogeneity of the protocols used. Finally, the results of this review cannot be extrapolated to the general population as it only analysed trained subjects and almost all subjects were men. All these limitations imply that the conclusions of this review should be interpreted with caution.

Conclusions

Although different protocols can be used to achieve post-activation potentiation, it seems that higher intensities induce better performance enhancement. Our results indicate that potentiation effect exists as long as minimum intensity and sufficient rest intervals are provided. More precisely, the results of this study highlight the following:

1. Experienced athletes benefit more from a higher volume potentiation bout (1-3 sets), especially when the optimal power load is used.
2. Intensities of 65% 1RM are valid with high volumes, but higher potentiation effects can be achieved with 85% - 90% 1RM intensities. Higher intensities are useful, but they need longer rest intervals.
3. Repetitions to failure or almost to failure are not recommended because of the fatigue generated (2-3 repetitions in reserve).
4. Around 7-8 minutes of rest should be allowed in order to dissipate fatigue. Self-selected rest intervals are valid too, as they adjust quite precisely.
5. Due to major sensitivity of type II fibres to calcium concentration, athletes with a higher percentage of type II fibres will benefit more from heavy loads and longer rest intervals after PAP protocols (Blazevich and Babault, 2019).
6. Plyometric protocols combined with short or medium rest intervals are useful post-activation protocols for the bench press.

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Study 2

<u>Garbisu-Hualde, A.</u>, Gutierrez, L., Fernández-Peña, E., & Santos-Concejero, J. (2023). Intermittent Voluntary Isometric Contractions Effects on Performance Enhancement and Sticking Region Kinematics in the Bench Press. *Journal of Human Kinetics*, *87*(1), 105-117.

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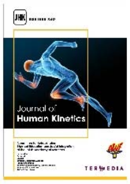

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Section III – Sports and Physical Activity

Intermittent Voluntary Isometric Contractions Effects on Performance Enhancement and Sticking Region Kinematics in the Bench Press

by
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During the last years, post-activation performance enhancement (PAPE) has gained notorious popularity due to the capacity to improve the acute rate of force development (RFD) using different strategies with different muscle contraction regimes as conditioning stimuli. The aim of the present study was to analyse the role of a maximal isometric post-activation performance enhancement (PAPE) protocol in performance and its effects on the kinematics of the sticking region. Twenty-one trained participants (age 26.4 ± 5.4 years) underwent two experimental sessions: an experimental session consisting of a single set and a single repetition of the bench press at the 93% of 1RM (which is considered a traditional conditioning activity to induce PAPE) (TRAD) and an isometric experimental session (ISO) consisting of 15 maximal voluntary isometric contractions in the sticking region of the medium grip bench press lasting 1 s with a 1 s rest interval between contractions. Both TRAD and ISO experimental conditions improved performance from post0 to post4, post8, post12 and post16, but only the ISO condition improved performance from the start of the lift to the start of the sticking region from pre to post ($p < 0.001$), and only the ISO condition improved maximum ($p = 0.005$) and minimum ($p = 0.025$) peak velocities. The results of this study suggest that short duration maximal voluntary isometric contractions improve the velocity of the lift prior to the initiation of the sticking region, which ultimately improves the impulse and facilitates the lift.

Keywords: *training; warm up; strength training; athletic performance*

Introduction

Post-activation performance enhancement (PAPE) is a phenomenon that acutely improves muscular performance after a conditioning activity (Blazevich and Babault, 2019). PAPE should not be confused with post-activation potentiation (PAP), even if both can be induced by voluntary contractions. Contrary to PAPE, which refers only to performance enhancements, PAP is confirmed via twitch verification tests (Cormier et al., 2022). PAPE is commonly achieved with heavy resistance exercises (the conditioning activity) prior to performing a biomechanically similar movement and its magnitude and duration depend on several factors, including the muscle fiber type, muscle temperature and sarcomere length (Blazevich and Babault, 2019). Due to major sensitivity of type II fibers to calcium concentration, athletes with a higher percentage of type II fibers will benefit more from high intensity PAPE protocols (Blazevich and Babault, 2019). Considering that the fiber type percentage is not fully inherited (Simoneau and Bouchard, 1995) and that training background can determine to a large extent fiber type proportion (Plotkin et al., 2021), interindividual differences in the response magnitude are acceptable.

During the last years, PAPE has gained notorious popularity due to the capacity to improve the acute rate of force development (RFD) using different strategies with different muscle contraction regimes as conditioning stimuli (Gepfert et al., 2019; Krzysztofik et al., 2020; Skurvydas et al., 2019). Various load protocols, such as optimal power loads (Gilbert and Lees,

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2005), medium loads (Lowery et al., 2012) and even plyometric exercises (Krzysztofik and Wilk, 2020) have been used. Regarding isometric contractions, current evidence suggests that 15 short, intermittent, and repetitive maximal voluntary contractions (15-MVC) seem to be the most effective isometric strategy to induce PAP (Skurvydas et al., 2019), as changes in the maximal voluntary contraction 10 min after the conditioning activity were highest under that condition. Interestingly, electrically induced twitch torque in 5-s sustained isometric contraction (MVC-5s) condition was higher than in 15-MVC condition (Skurvydas et al., 2019). However, since those results were obtained bypassing the nervous system fatigue with electrical stimulation, we decided to test the protocol that achieved better results in the voluntary contraction test.

Some studies including lower limb exercises, which focused on isometric contractions as potentiation stimuli, have been already performed . Bogdanis et al. (2014) compared the effects of concentric, eccentric and isometric half-squat protocols on countermovement vertical jump performance and they concluded that 3 sets of 3 s of maximal isometric force (with a 1 min rest interval between sets) improved countermovement vertical jump performance by about 3%. Another study (Vargas-Molina et al., 2021) extends those results demonstrating that both concentric (2 sets of 3 repetitions at 75% 1RM) and isometric (2 sets of 4 s with a load equivalent to 75% 1RM) PAPE protocols improved performance in the countermovement jump. On the other hand, Tsolakis et al. (2011) compared the effectiveness of an isometric protocol consisting of 3 sets of 3 s of maximal isometric contractions separated by 15-s rest intervals in the upper and lower body. In this case, upper body performance did not change compared to baseline, and lower body performance decreased showing a negative correlation between leg force and peak leg power.

The sticking region is the weakest region in the range of motion of any lift (Kompf and Arandjelović, 2017). Several strategies have been proposed in the literature to face it, which include additional loading in that specific region using elastic bands or chains, and also increasing the impulse prior to the sticking region (Kompf and Arandjelović, 2016). Based on Lum and Barbosa (2019), isometric strength training can produce strength improvements in joint angles up to 20^0–50^0 away from the joint angles used during isometric training. Therefore, the question arises whether protocols used by Skurvydas et al. (2019) are effective when used with the intention to acutely improve the impulse before and in the sticking region, and whether there are any differences compared to previous protocols (Bogdanis et al., 2014; Tsolakis et al., 2011). In this regard, the barbell bench press, one of the most popular resistance exercises for upper limbs and one of the three main lifts in powerlifting competitions (Gomo and Tillaar, 2016), appears to be an interesting option to answer this question.

Thus, the aims of this study were: i) to determine whether an isometric PAPE protocol is applicable to field conditions for the medium grip bench press, and ii) to observe whether any changes occur in the kinematics of the sticking region due to the PAPE protocol. We hypothesized that i) an isometric protocol would imply higher velocities of the first half of the lift (i.e., improvements seen by Lum and Barbosa (2019) after several weeks extrapolated to a single session, acute force improvements in trained joint angles and nearby), what would make the lift easier due to a higher impulse prior to the sticking region, and ii) this would be reflected in improved performance or a shortened sticking region.

Methods

Participants

Twenty-one participants (age 26.4 ± 5.4 years; body mass 79.4 ± 9.7 kg; body height 176.2 ± 6.9 cm; medium grip bench press 1 repetition maximum (1RM) 97.4 ± 19.8 kg; relative strength (1RM/body mass) 1.22 ± 1.9) with at least two years of resistance training experience voluntarily took part in this study. Participants were required to meet the following inclusion criteria: 1) men between the age of 18–40 years; 2) lack of musculoskeletal disorders or injury in the previous 6 months; 3) experienced in resistance training, defined as consistently lifting weights at least 3 times per week for a minimum of 2 years. A total of 20 participants completed the study: one participant dropped out prior to completion due to personal reasons. We did not control for nutrition nor hydration levels, but participants were told not to make any changes in the above during the testing period. Participants were asked to refrain from training 48 h before each testing session and not to take caffeine. All participants performed the three sessions at the same time of the day with at least 48 h of rest between sessions. Written informed consent was obtained from each participant after a thorough explanation of the testing protocol, the possible risks involved, and the right to terminate participation at will. The study was conducted according to the Declaration of Helsinki, and the Institutional Review Board of the University of the Basque Country (UPV/EHU) approved the experimental protocol.

Procedures

Participants visited the laboratory on three separated occasions. Prior to every experimental session and the 1RM test, participants performed a standardised warm-up protocol, consisting of 5 min of cycling and bench press warm-up sets consisting of 1 set of 12 repetitions with the barbell only, followed by 3 sets of 8, 6 and 3 repetitions with 40%, 60% and 75% 1RM, respectively. The rest interval between warm-up sets was to 2 min. In every session, during the bench press, participants performed the descent with a 2 s tempo, followed by a 1 s pause in the chest with help of a metronome at 60 beats per minute (BPM) to standardise repetitions. Participants were instructed to perform the concentric phase as fast as possible. Bench press grip width was set at 1.4 times biacromial distance as described elsewhere (Larsen et al., 2021).

1RM Calculation

During the first visit, participants underwent a direct 1RM test for the bench press. The 1RM was defined as the highest load lifted by participants without any compensatory movement and only if they completed the pause on the chest properly. When an attempt was successful, the next attempt was decided asking the participant and evaluating the reported mean propulsive velocity by the velocity linear transducer (Speed4Lifts, Spain) (Pérez-Castilla et al., 2019). Participants rested for 3 min between attempts. The test finished when participants reported a rate of perceived exertion (RPE) of 10 in the repetitions in the reserve based RPE scale (Helms et al., 2016). If participants failed an attempt, the weight was reduced by 2.5 kg and another attempt was performed after a 3-min rest interval.

Sticking Region Identification

In addition, each lift during familiarization was recorded from a side view at 300 Hz using an active LED marker on the barbell's edge and a high-speed video camera (Casio ExilimEX-F1). Video recordings were analysed using kinematic analysis software Kinovea (version 0.8.15), which is valid, precise, and reliable (Puig-Divi et al., 2019). Data exported from Kinovea to Excel (version 16.16.27) were filtered (Butterworth low pass filter at 5 Hz) and then used to determine where the sticking region was, defined as the region of the lift between the first peak ($V_{max\ peak}$) in velocity and the first minimum after the peak ($V_{min\ peak}$) (Escamilla et al., 2000). This region varies inter-individually due to differences in the anatomical cross-sectional area of the muscle, force-length relationship, force-velocity relationship, fatigue, motor unit recruitment, fiber type and biomechanical factors that affect torque development (Kompf and Arandjelović, 2016).

Once the sticking region was detected, the height of the barbell at this region was calculated. Since the sticking region is not a particular point, but a range of motion of the lift, to ensure that the isometric contraction affected the sticking region, the protocol was performed in the middle of this region, as isometric contractions had been demonstrated to strengthen 20º–50º away from the adopted joint angles (Lum and Barbosa, 2019).

Conditioning Activities

Measurements of the experimental conditions lasted 45 min and were scheduled one week after the first visit to the laboratory. The study followed a within-subject design, where each participant was his own control. In this way, in both experimental sessions, participants performed a pre-conditioning lift (control lift), a conditioning activity and several post-conditioning lifts. Thus, on the second day, participants were randomly assigned to one of the following two experimental conditions: an isometric contraction conditioning protocol (ISO) or a traditional conditioning protocol (TRAD). Volume was not matched between conditioning activities. On the third session, participants changed experimental conditions. After completing the conditioning protocol (ISO or TRAD), participants were asked for the RPE.

Each experimental session consisted of a standardised warm-up protocol followed by a 3-min rest interval and a pre-conditioning lift (control lift), which consisted of 1 set of 1 repetition of the bench press at 85% 1RM. After the pre-conditioning lift, participants rested for 3 min, and then they proceeded with the conditioning activity to which they were randomly assigned.

The ISO conditioning activity consisted of 15 maximal voluntary isometric contractions (MVIC) of 1 s with a 1-s rest interval between contractions (Skurvydas et al., 2019) at their sticking region as previously described. Participants were encouraged to exert force as fast as possible. Isometric contractions were performed by fixing the barbell of a Smith machine at the appropriate height (using a 11 mm diameter rock climbing rope) to match the middle of the sticking region height. The TRAD conditioning activity consisted of 1 set of 1 repetition with 93% of their estimated 1RM of the familiarisation day (Garbisu-Hualde and Santos-Concejero, 2021).

Post-conditioning measurements (1 set of 1 repetition of the bench press at 85% 1RM) were recorded 0, 4, 8, 12 and 16 minutes later (post0, post4, post8, post12 and post16) (Lowery et al., 2012; Mina et al., 2019) using the same velocity linear transducer. Participants were instructed to lift the barbell as fast as possible during the ascending phase of the movement.

If participants improved performance from pre-conditioning to any of the post-conditioning lifts, they were chosen for further analysis of the sticking region kinematics. This distinction between responders and non-responders to the conditioning activity was based on the calculated smallest meaningful difference. When the difference in the best post-conditioning lift and the pre-conditioning lift was higher than the smallest meaningful difference, participants were considered responders and chosen for analysis of the sticking region.

Statistical Analyses

Data were screened for normality of distribution using the Shapiro-Wilk test. Two-way ANOVA with repeated measures (lift × time) was used to determine if any of the post-conditioning lifts improved performance under each experimental condition and to compare same time points across experimental conditions (ISO vs. TRAD). The magnitude of differences of effect sizes (ES) was calculated using Cohen's d (Cohen, 1988) and interpreted as small (>0.2 and <0.6), moderate (≥0.6 and <1.2) and large (≥1.2 and <2) or very large (≥2) according to Hopkins et al. (2009). All statistical analyses were performed using Prism 9 for Mac. Significance for all analyses was set at $p < 0.05$. 95% confidence intervals were reported as 95% [Lower limit, Upper limit]. Additionally, for those participants for whom the conditioning activity improved performance (responders), the velocity until the first peak was measured and compared using one-way ANOVA with repeated measures (lift × time), comparing pre-conditioning velocity, post0 velocity and velocity of the fastest time point. To select those responders, we calculated the smallest meaningful difference following the formula below:

$$\sqrt{\frac{2 \cdot \sigma^2}{n}} \cdot \left(z_{1-\beta} + z_{1-\frac{\alpha}{2}}\right)$$

The reported results by the formula were smaller (e.g., measured smallest meaningful difference = 0.005 m·s^{-1}) than values reported by the used velocity linear transducer (e.g., 0.23 m·s^{-1}). Thus, if any participant improved performance in any post-conditioning lift (e.g., from 0.23 m·s^{-1} to 0.24 m·s^{-1}), the difference must have been higher than the calculated smallest meaningful difference. We also performed a Fisher´s exact test to compare if there was a significant difference between the number of responders and non-responders to the conditioning activity in ISO and TRAD groups.

Results

Kinematics of the Sticking Region

To analyse changes in the kinematics of the sticking region, participants who improved performance in any time point (i.e., responders) were analysed, even if statistical significance was not reached. The Fisher´s exact test reported a significant difference between the number of responders and non-responders ($p = 0.001$). Thus, seven subjects were analysed for the TRAD condition and 17 for the ISO condition.

When comparing mean velocity from the start of the ascending phase until the first maximum peak in velocity (pre-sticking region), no differences were found in the TRAD experimental condition for responders ($n = 7$;

33.33% of participants) (p = 0.229; 95% CI [−0.1545, 0.035]) (Figure 2A).

In contrast, when comparing the velocity from the start of the ascending phase until the first maximum peak in velocity under the ISO experimental condition in the same time points, we found that for responders (n = 17; 85% of participants), the first maximum peak in velocity was higher in the fastest time point (i.e., higher velocities were achieved prior to the initiation of the sticking region) (p < 0.001; ES = 0.67; 95% CI [0.07, 0.02]). However, when comparing the first maximum peak in velocity from pre- with the first maximum peak in velocity in the slowest time point (post0), we found that in the slowest time point, the first maximum peak was smaller (lower velocities were recorded prior to the initiation of the sticking region) (p = 0.004; ES = 0.64; 95% CI [−0.012, −0.063]). Additionally, the ascending phase velocity until the first maximum peak in the fastest time point was higher than in the post0 time point (p < 0.0001; ES = 1.22; 95% CI [0.112, 0.053]) (Figure 2B).

We compared $V_{max\ peak}$ and $V_{min\ peak}$ from pre- to the fastest post-conditioning lift of each participant for whom either the TRAD or the ISO experimental condition was effective. The TRAD experimental condition showed no improvements in $V_{max\ peak}$ (p = 0.457; ES = 0.37; 95% CI [−0.074, 0.146]), nor in $V_{min\ peak}$ (p = 0.125; ES = 0.85; 95% CI [−0.0271, 0.173]), while the ISO experimental condition showed improvements in both $V_{max\ peak}$ (p = 0.005; ES = 0.71; 95% CI [0.02, 0.093]) and $V_{min\ peak}$ (p = 0.025; ES = 0.38; 95% CI [0.006, 0.072]) (Figures 3A–D).

Mean Velocity Changes and RPE

When comparing the mean propulsive velocity between pre- and all post-conditioning lifts, we found that post0 was slower than pre- in both TRAD (p = 0.002; ES = 0.74; 95% CI [−0.0136, −0.073]) (Figure 4A) and ISO experimental conditions (p < 0.001; ES = 1.53; 95% CI [−0.067, −0.153]) (Figure 4B). The TRAD protocol reported an average RPE (rate of perceived exertion) of 7.3 ± 0.7, while the ISO protocol reported an average RPE of 7.0 ± 1.0. None of the post-measurements reached statistical significance compared to pre-conditioning values. When comparing the same time points across experimental conditions (ISO vs. TRAD), there was only a significant result in post0, where the ISO condition induced slower performance than the TRAD condition (0.37 $m \cdot s^{-1}$ vs. 0.3 $m \cdot s^{-1}$; p = 0.01; ES = 1.07; 95% CI [0.01219, 0.01217]).

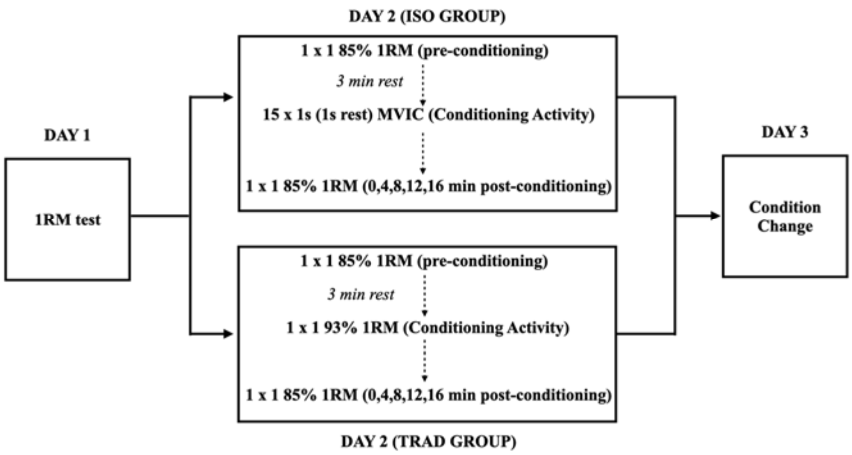


Figure 1. Scheme of the followed investigation procedure.

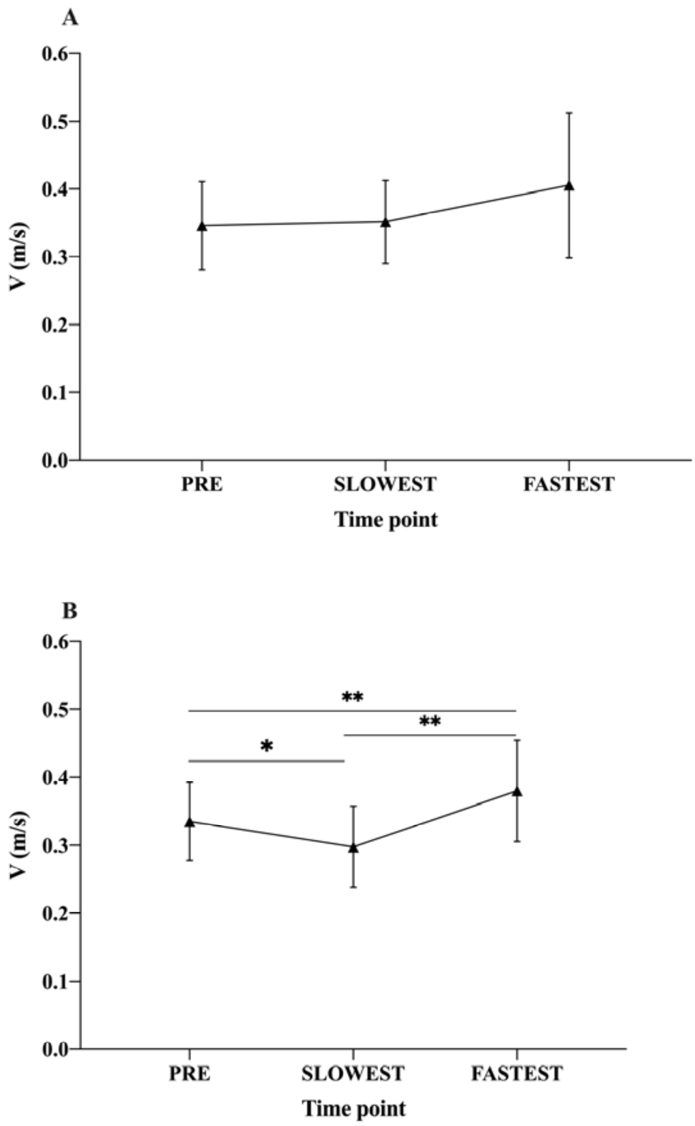


Figure 2. Lifting velocities pre-conditioning and in the slowest and fastest post-conditioning activity time points. (A) TRAD post-activation performance enhancement experimental session. (B) ISO post-activation performance enhancement experimental session.
$* p < 0.05$; $** p < 0.001$

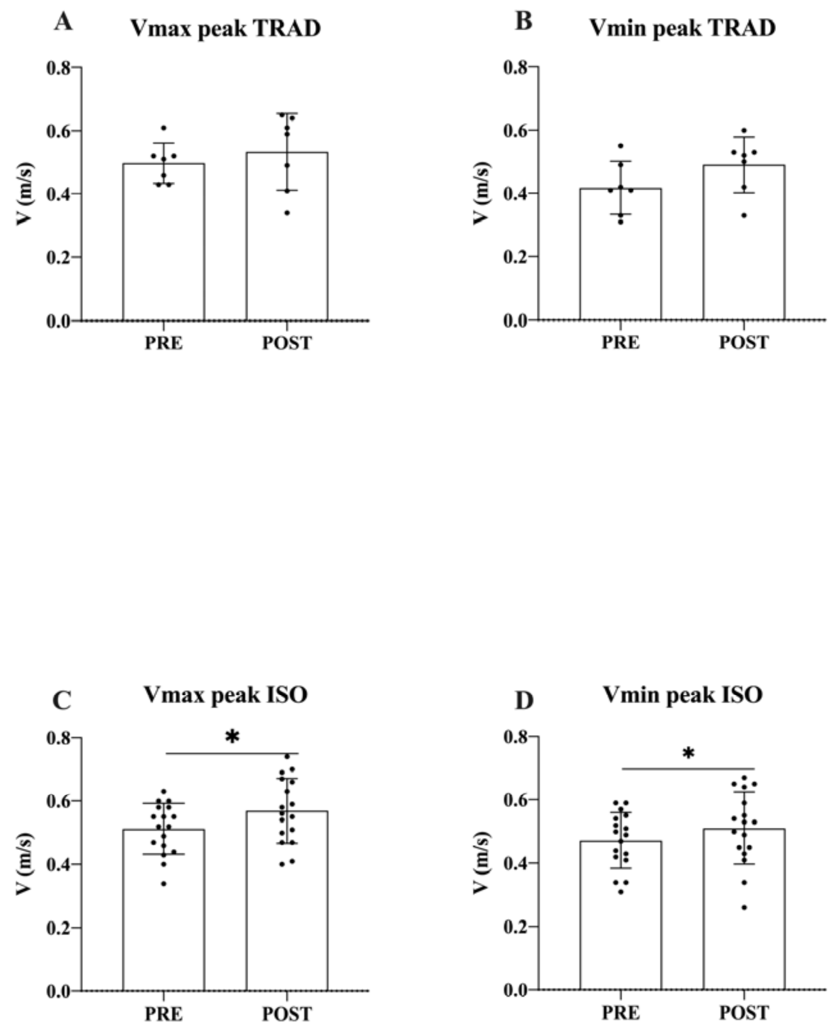
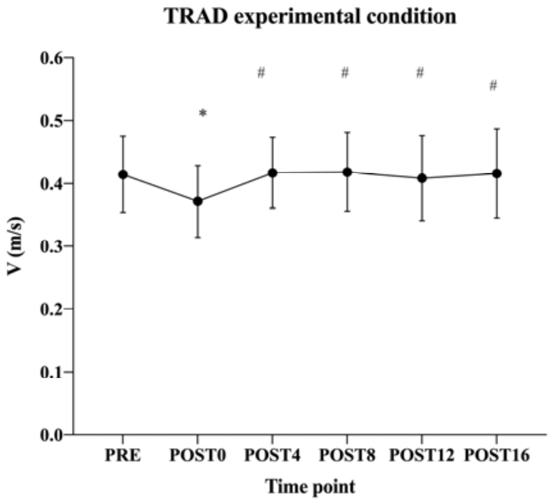


Figure 3. (A) First peak in the velocity of the load (V_{max}) in pre- and the fastest post-conditioning lift in TRAD. (B) First local minimum velocity peak (V_{min}) in pre- and the fastest post-conditioning lift in TRAD. (C) $V_{max\ peak}$ in pre- and the fastest post-conditioning lift in ISO. (D) $V_{min\ peak}$ in pre- and the fastest post-conditioning lift in ISO.
* $p < 0.05$

A



B

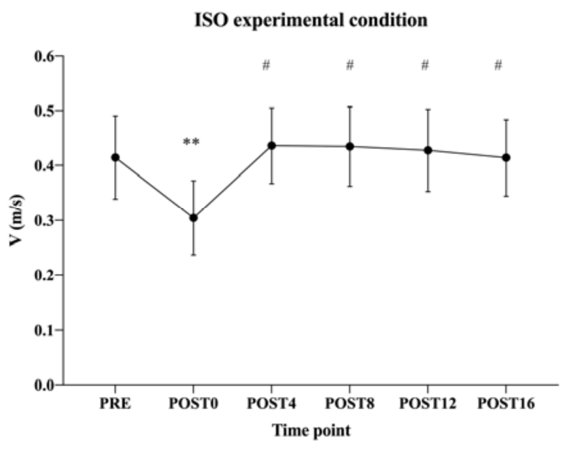


Figure 4. Lifting velocities pre and post 0, 4, 8, 12 and 16 minutes. (A) Mean TRAD post-activation performance enhancement experimental session values. (B) Mean ISO post-activation performance enhancement experimental session.
*Significantly different from pre * ($p < 0.05$) or ** ($p < 0.001$) and # post0 ($p < 0.001$)*

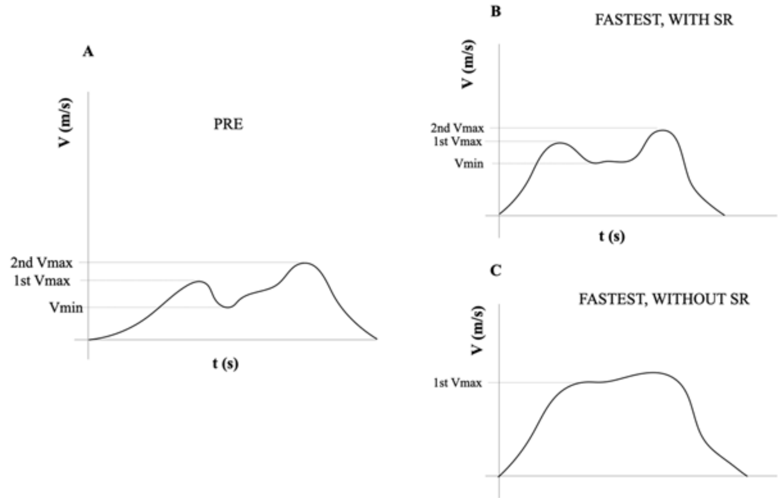


Figure 5. (A) Illustration of a typical Sticking Region velocity-time profile, which could be observed in pre-conditioning lifts. (B) Illustration of a Sticking Region velocity-time profile post-conditioning, with enhanced the first peak in the velocity of the load (V_{max}) and its first local minimum peak thereafter (V_{min}). (C) Illustration of a post-conditioning lift where the impulse prior to the initiation of the Sticking Region is augmented to the point that no velocity loss occurs and, thus, V_{min} disappears.

Discussion

The findings of this study support one of our two hypotheses, i.e., the kinematics and the characteristics of the sticking region change considerably (Figure 5 A–C) after the ISO conditioning protocol, however, mean propulsive velocity remains unchanged.

The main finding of this study was that an isometric PAPE protocol improved sticking region kinematics in the first part of the range of motion of the medium grip bench press. This improvement is evident in the first period of the ascending phase, prior to the sticking region, which helps the lifter to overcome that sticking region (Kompf and Arandjelović, 2016). The main enhancement is that the first maximum velocity peak is greater after the ISO conditioning protocol (Figure 3C), which provides the lifter with a greater impulse to overcome the sticking region. Also, the minimum velocity is higher after the ISO conditioning protocol (Figure 3D). The augmented first maximum and minimum velocity peaks result in a change in the velocity-time profile of the lift (Figure 5 A–C). This change in the velocity-time profile of the lift and the sticking region (i.e., less velocity loss from maximum to minimum velocity points) is due to the greater impulse that the lifter has achieved prior to the sticking region. The improvement in the first part of the lift can provide the lifter with enough impulse to avoid excessive velocity loss from $V_{max\ peak}$ to $V_{min\ peak}$, making the sticking region imperceptible (Figure 5C).

The ISO conditioning protocol improved performance in more participants (85%) than the traditional conditioning protocol (33.33%), which could be related to the interaction between stimuli and fatigue (Chiu and Barnes, 2003). Recruitment of type II fibers is needed to achieve PAPE, which is the result of a correct selection of intensity (Garbisu-Hualde and Santos-Concejero, 2021). The TRAD conditioning protocol implied a higher RPE than the ISO conditioning protocol (ES = 0.36). Nonetheless, in both conditioning protocols, participants reported an RPE of 7, which is in line with previous research (Garbisu-Hualde and Santos-Concejero, 2021). The ISO conditioning protocol includes 1-s rest intervals, which via the reduction in inorganic phosphate accumulation could help reduce excessive fatigue (Skurvydas et al., 2019).

It is worth mentioning that the ISO conditioning protocol produced a greater decrease in performance immediately post conditioning (post0) compared to the TRAD protocol. This could be due to the total time under tension, which is greater in the ISO conditioning protocol (15 s in total). However, in contrast to the TRAD conditioning protocol, improvements in velocity until the initiation of the sticking region were found in the ISO conditioning protocol, which suggests that isometric contractions produce less fatigue than dynamic contractions, or that subjects recover from the produced fatigue faster (Lum and Barbosa, 2019). This lower cumulative fatigue may be due to the lower consumption of ATP in lengthened and isometric contractions compared to shortening contractions (Beltman et al., 2004). Regarding the neural factors limiting maximal force production, it is widely accepted that motor unit recruitment strategies play a key role (Farina and Negro, 2015). The origin of this central fatigue could be at the spinal level, due to inhibitory intramuscular afferents (i.e., group Ia and II muscle afferents) and recurrent inhibition by Renshaw cells (Gandevia, 2001).

We must acknowledge some limitations. Considering that a linear encoder provides the mean propulsive velocity (Pareja-Blanco et al., 2017) and that the minimum mean propulsive velocity for a successful lift in the bench press has been calculated (González-Badillo et al., 2011), more velocity implies more distance from that mean minimum propulsive velocity, and thus, furthers subjects failure. Unfortunately, changes in magnitude (e.g., from 0.27 $m \cdot s^{-1}$ to 0.29 $m \cdot s^{-1}$) were so small that statistical significance was not reached. Nevertheless, when comparing instantaneous velocities, magnitude changes were greater (e.g., from 0.26 $m \cdot s^{-1}$ to 0.34 $m \cdot s^{-1}$). Also, the selected intensity for the control lift (85% 1RM) was high. Even if notorious mean propulsive velocity changes are hard to see at those intensities, 85% 1RM was chosen for two main reasons: (i) higher similarity to real strength training or competition, and (ii) this is the minimum intensity needed to record a sticking region (Tillaar et al., 2014), which was one of the intentions of the study. Finally, it is worth mentioning that this study does not include a classic control group with no conditioning activity carried out. These limitations imply that conclusions of this study should be interpreted with caution.

Conclusions

In conclusion, the results of this study suggest that short lasting maximal voluntary isometric contractions (15 x 1-s MVICs interspersed with 1-s rest intervals) result in better pre-sticking region kinematics, which could lead to reduced RPEs reported by athletes. It could be very useful when a rapid potentiation is needed, when athletes have not much time between the warm-up and the competition lift or when athletes feel insecure about managing heavy weights.

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Study 3

Garbisu-Hualde, A., Gutierrez, L., & Santos-Concejero, J. (2023). Post-Activation Performance Enhancement as a strategy to improve bench press performance to volitional failure. *Journal of Human Kinetics*, *88*(1), epub ahead of print.

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Post-Activation Performance Enhancement as a Strategy to Improve Bench Press Performance to Volitional Failure

by

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Post-Activation Performance Enhancement (PAPE) has been commonly used as a strategy to improve acute force production, although its effects on performance to volitional failure are still unknown. The aim of this study was to analyse the influence of a PAPE protocol on bench press performance in a training set to volitional failure in trained individuals. Fourteen participants with at least two years of resistance training experience (age 24.57 ± 2.7 years; body mass 77.47 ± 12.2 kg; body height 174.21 ± 7.4 cm; medium grip bench press 1 repetition maximum (1RM): 101.6 ± 25.8 kg), of which 14 completed the control protocol and 12 completed the experimental protocol, took part in the study. After a standardised warm-up, participants completed three sessions: 1) a 1RM test for the medium grip bench press, 2) a control condition consisting of a set of the bench press to volitional failure with 80% 1RM (CON), and 3) an experimental condition consisting of a set of the bench press to volitional failure with 80% 1RM after a PAPE protocol (PAPE). The PAPE protocol consisted of a heavy set of one repetition with their 93% 1RM as the conditioning activity. Under the PAPE condition, participants performed significantly more repetitions than under the CON condition ($p = 0.008$, ES = 0.5, small effect), their last repetition was slower ($p = 0.02$, ES = 0.52, small effect) and presented a higher velocity loss ($p = 0.004$, ES = 0.75, moderate effect). These results suggest that a traditional PAPE protocol improves the number of repetitions performed to volitional failure.

Keywords: *muscle hypertrophy; strength training; AMRAP; muscle endurance*

Introduction

Improving sport performance requires correctly combining different aspects through a training program. Several strategies are commonly used to improve acute force production in explosive tasks (McGowan et al., 2015) or exercise volume in tasks to volitional failure (Alves et al., 2019), and Post-Activation Performance Enhancement (PAPE) is one of such strategies. PAPE has been defined as a phenomenon that acutely improves voluntary muscle performance (Blazevich and Babault, 2019). PAPE should not be confused with Post-Activation Potentiation (PAP), which needs electrically induced confirmation (Cuenca-Fernández et al., 2017; MacIntosh et al., 2012). Mechanisms behind PAPE are not completely known, but evidence suggests that it may be due to a combination of the mechanism behind PAP (i.e., myosin light chain phosphorylation) and other mechanisms such as muscle temperature or intramuscular water content (Blazevich and Babault, 2019; Rodrigues et al., 2022). Most commonly, the used conditioning activity (CA) and the exercise where performance enhancement is required are biomechanically similar (i.e., a barbell back squat as a CA for squat jumps), as it is more likely to obtain favourable performance results (Cormier et al., 2022). Regarding rest intervals, various recommendations have been proposed, but in a recent study by Cormier et al. (2022), 5–7 minutes are recommended for strong individuals (≥1.35 kg/kg [1RM kg / body mass in kg] in the barbell bench press) and ≥8 minutes for weaker individuals.

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PAPE has gained notorious popularity in power related sports due to its capacity to improve the acute rate of force development using different strategies with different muscle contraction regimes as conditioning stimuli (Krzysztofik et al., 2020a; Skurvydas et al., 2019). Various load protocols, such as optimal power loads (5 repetitions of the back squat with the optimum power load with 5 min rest intervals between repetitions) (Gilbert and Lees, 2005), medium loads (4 repetitions of the back squat with 70% 1RM) (Lowery et al., 2012) and even plyometric contractions (3 sets of 5 repetitions of plyometric push-ups with a 1-min rest interval) (Krzysztofik and Wilk, 2020) can be used. Even more, PAPE has started to be studied as an acute mechanism to improve the total volume performed during a training session (Alves et al., 2019; Krzysztofik et al., 2020b). In a study by Alves et al. (2019), a PAP protocol consisting of 3 sets of 1 repetition of the bench press exercise at 90% 1RM showed a performance enhancement in a task to volitional failure in the first two sets compared to a control condition. On the other hand, results by Krzysztofik et al. (2020b) showed no improvement in the number of performed repetitions between PAPE (3 sets of 3 repetitions of the bench press at 85% 1RM) and control conditions, but they found a higher time under tension for the PAPE condition. Evidence so far seems contradictory and scarce, thus, the possible role of PAPE to increase training volume is yet to be elucidated

Velocity-based training is a well-known method to quantify a strength training stimulus (González-Badillo et al., 2011; Martínez-Cava et al., 2020). Previous research has suggested that PAPE can improve skeletal muscle shortening velocity due to improved Ca^{2+} sensitivity (Boullosa et al., 2018). This results in increased propulsive velocity (Blazevich and Babault, 2019), which may improve the performance of all repetitions in a set to volitional failure, helping the athlete to complete more repetitions at the same intensity. As PAPE has previously demonstrated to improve performance in a task to volitional failure (Alves et al., 2019), the question arises whether this improvement is related to a greater velocity loss between the first and the last performed repetition during a set of the bench press exercise.

PAPE is especially useful in sport performance during submaximal loaded tasks such as sprinting (Iacono et al., 2018), jumping (Lowery et al., 2012) and throwing (Krzysztofik et al., 2022), possibly due to a greater sensitivity to submaximal Ca^{2+} concentrations (Blazevich and Babault, 2019). As most studies show improvements in short-lasting activities, it would be of great interest to analyse what happens when work capacity is tested in a submaximal loaded task, considering the number of repetitions performed until volitional failure. The barbell bench press, one of the most popular exercises for upper body strength and one of the three main lifts in powerlifting competitions (Gomo and Tillaar, 2016), appears to be an interesting choice to answer these questions. Thus, this study aimed to analyse the influence of a traditional PAPE protocol on performance in a set at 80% 1RM, total work performed and last repetition kinematics in a training set to volitional failure in the bench press exercise. Our hypothesis was that, as PAPE protocols are effective in submaximal loads, the number of performed repetitions would be higher under the PAPE condition.

Methods

Participants

Fourteen participants (age 24.57 ± 2.7 years; body mass 77.47 ± 12.2 kg; body height 174.21 ± 7.4 cm; medium grip bench press 1 repetition maximum (1RM) 101.6 ± 25.8 kg) with at least 2 years of resistance training experience voluntarily took part in the study. Participants were required to meet the following inclusion criteria: 1) males between the age of 18 and 40 years; 2) lack of musculoskeletal disorders or injury in the previous 6 months; 3) resistance training experience, defined as consistently lifting weights at least 3 times per week for a minimum of 2 years. Fourteen participants met the inclusion criteria and were recruited for the study, from which a total of 14 completed the control protocol and 12 participants completed the experimental protocol. Written informed consent was obtained from each participant after a thorough explanation of the testing protocol, the possible risks involved, and the right to terminate participation at will. The study was conducted according to the Declaration of Helsinki, and the Institutional Review Board of the University of the Basque Country (UPV/EHU) (Ref. CEISH 117/2019).

Design and Procedures

Participants visited the laboratory on three separated occasions. Prior to every experimental session, participants performed a standardised warm-up consisting of 5-min cycling on a cycloergometer and bench press sets including 10 repetitions with 40% 1RM, four repetitions with 60% 1RM, two repetitions with 70% 1RM, and one repetition with 80% 1RM, as described elsewhere (Krzysztofik et al., 2020a). During the first visit, participants underwent a 1RM test for the medium grip bench press. The 1RM test was performed in the free weight bench press and grip width was set at 1.4 times biacromial distance as described elsewhere (Larsen et al., 2021). In every session, participants were requested to perform a 2-s tempo descent followed by a 1-s pause on the chest (using a metronome at 60 beats per minute) to standardise the repetitions (Krzysztofik et al., 2020a). The 1RM was defined as the highest load lifted by the participant without any compensatory movement only if the participant completed the pause on the chest properly. When an attempt was successful, the next attempt was performed evaluating the reported mean propulsive velocity by the linear encoder T-Force Dynamic Measurement System (ERGOTECH, Murcia, Spain) (Martínez-Cava et al., 2020).

After 72 hours, participants were randomly assigned (www.random.org) to a PAPE (experimental condition) or a CON (control condition) group. The second and third experimental sessions were scheduled 72 hours apart to allow full recovery, and at the same time of the day. During the CON protocol, participants underwent a standardised warm-up, and 4 min after the last approximation set, they performed repetitions until concentric volitional failure with their 80% 1RM. During the PAPE protocol, participants underwent the same standardised warm-up, but they performed a heavy set of one repetition with their 93% 1RM as a conditioning activity (Garbisu-Hualde and Santos-Concejero, 2021) and then were asked for their rate of perceived exertion (RPE). After the conditioning activity, participants rested for 6 min before performing repetitions until concentric volitional failure with their 80% 1RM. The conditioning activity settings (rest interval and the protocol used) were based on the participants′ strength level. This configuration was chosen because participants′ strength levels (1.31 kg/kg) were closer to high strength levels reported by Cormier et al. (2022) (≥1.35 kg/kg [1RM kg/body mass in kg] in the barbell bench press). Participants performed a 2-s tempo descent followed by a 1-s pause on the chest (using a metronome set at 60 beats per minute) during all repetitions, to avoid compensatory movements and not to alter the obtained results. Mean propulsive velocity of the lifts was measured with the linear encoder T-Force Dynamic Measurement System. For the third session, participants changed the conditions. Participants were instructed to lift the barbell as fast as possible during the ascent of all testing lifts, and were requested not to perform any exhausting activity 48 hours prior to the intervention. They were also requested not to consume caffeine or any other stimulant prior to testing.

Statistical Analysis

Data are presented as means ± SD. All variables presented a normal distribution according to the Shapiro-Wilk test. A paired *t*-test was performed to compare the experimental with and the control condition. Additionally, the magnitude of differences of effect sizes (ES) was calculated using Cohen’s *d* (Cohen, 1988) and interpreted as small (>0.2 and <0.6), moderate (≥0.6 and <1.2) and large (≥1.2 and <2) or very large (≥2) according to the scale proposed by Hopkins et al. (2009). All statistical analyses were performed using Prism 9 for Mac. Significance for all analyses was set at $p < 0.05$.

Results

When comparing the number of repetitions performed until concentric volitional failure in a set with 80% of the 1RM, participants performed significantly more repetitions (10.83 ± 2.5 repetitions) under the PAPE condition than under the CON condition (9.76 ± 1.72 repetitions) ($p = 0.008$; ES = 0.5, small effect) (Figure 1).

The mean propulsive velocity of the last repetition prior to the concentric volitional failure was significantly lower under the PAPE condition (0.16 ± 0.06 $m \cdot s^{-1}$) than the CON condition (0.2 ± 0.09 $m \cdot s^{-1}$) ($p = 0.02$; ES = 0.52, small effect) (Figure 2). No differences were found in mean propulsive velocity of the first repetition between the PAPE (0.43 ± 0.1 $m \cdot s^{-1}$) and the CON condition (0.42 ± 0.13 $m \cdot s^{-1}$) ($p = 0.582$; ES = 0.09, small effect). Velocity loss from the first to the last repetition was significantly greater under the PAPE condition (0.27 ± 0.05 m·s^{-1}) compared to the CON condition (0.22 ± 0.08 m·s^{-1}) (p = 0.004; ES = 0.75, moderate effect).

The average reported RPE under the PAPE condition for the conditioning activity was 7.17 ± 0.58, and the achieved mean propulsive velocity in the conditioning activity was 0.30 ± 0.12 m·s^{-1}.

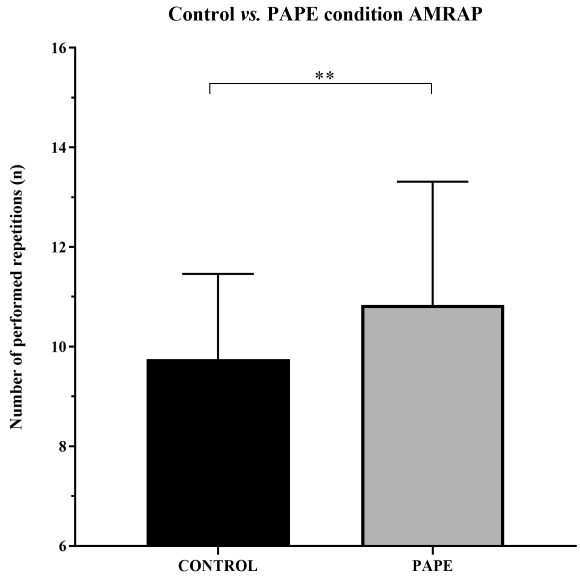

Figure 1. Total number of repetitions performed until volitional failure with 80% 1RM in the CON (control) and PAPE (experimental) conditions.
*** $p < 0.001$*

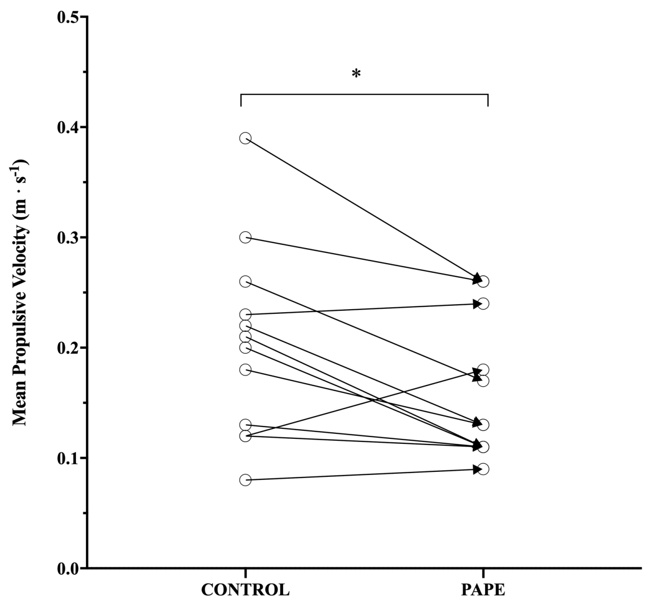

Figure 2. Mean propulsive velocity (m·s^{-1}) of the last repetition of the performed set to volitional failure with 80% 1RM in the CON (control) and PAPE (experimental) conditions.
** $p < 0.05$*

Discussion

The main finding of this study was that performing a traditional PAPE protocol consisting of a single set of a single repetition with 93% 1RM (Garbisu-Hualde and Santos-Concejero, 2021) improved bench press performance, measured as the number of repetitions performed to volitional failure. These results are in agreement with previous research (Alves et al., 2019).

Performing a traditional PAPE protocol prior to a set to volitional failure could make the athlete acutely more resistant to fatigue in long-lasting tasks (in our case, a set to volitional failure of various repetitions) (Bompa and Buzzichelli, 2016). The exact rationale behind this improvement in performance is not fully elucidated. Temperature increases are a commonly mentioned mechanism behind performance enhancement, but based on the results of Weigert et al. (2018), where small and non-significant temperature changes were seen after 10 repetitions at 70% in a biceps curl, it seems unlikely. Nevertheless, Boullosa et al. (2018) mention a possible mechanism, where the elevation of Ca^{2+} levels increases due to low-frequency twitches, what can cause the performance enhancement independent of myosin regulatory light chain phosphorylation.

Interestingly, performance improvements observed in this study may be related to improved capacity to perform slower repetitions, as under the PAPE condition, participants performed, on average, one more repetition, which was slower than under the CON condition (Figure 2). In consequence, the velocity loss was greater from the first to the last repetition. The attempt to complete one more repetition so close to failure could be due to psychological reasons (Szalma and Hancock, 2011). The maximal adaptability theory (Szalma and Hancock, 2011) states that hyperstress situations could lead to bad performance. In this way, those last, hard, and slow repetitions would be the stressing situations where participants need to strive to fulfil the lift. Performing the conditioning activity in the PAPE protocol (a heavy repetition prior to the tested task), could improve participants´ confidence when struggling with those last repetitions (Szalma and Hancock, 2011). Another possible explanation for the performance improvement observed could be the training velocity specificity, which means that after performing that specific conditioning activity, participants gain acute fitness or adapt acutely to low velocity lifting (Behm and Sale, 1993).

The quantity of work performed per session, understood as the total number of sets (Baz-Valle et al., 2022) or the volume load (sets x repetitions x kilogram) (Schoenfeld et al., 2014), is related to the quantity of gained muscle mass. Thus, if PAPE leads to an increased number of repetitions performed until failure, the volume load per session would be improved, and so could muscle hypertrophy. Following this line of reasoning, it could also be assumed that hypothetic muscle hypertrophy benefits could be due to both the improved mechanical tension of the last repetition (due to obtained lower mean propulsive velocities, Figure 2) and a greater number of performed repetitions (Figure 1). This means that the performed additional repetition may be effective when aiming at muscle hypertrophy. Previous studies support the notion that with a greater velocity loss, muscle hypertrophy gains can be more significant (Pareja-Blanco et al., 2017), but only to some extent (Andersen et al., 2021; Pareja-Blanco et al., 2020). Evidence suggests that when velocity loss is excessive (40%), subsequent sets could be affected (Pareja-Blanco et al., 2020). This is in line with findings of Alves et al. (2019), where significant differences were found in the number of repetitions performed in the first (PAP = 11.5 ± 3.1; CON = 10.4 ± 2.7; $p < 0.05$; ES = 0.38) and the second (PAP = 6.5 ± 1.9; CON = 5.5 ± 1.8; $p < 0.05$; ES = 0.54) set between PAP and CON groups, but not in the third set. This suggests that performance enhancement can increase training volume significantly, but when velocity loss is too pronounced, fatigue may overcome potentiation and impair performance in subsequent sets. Our study is in line with that by Krzysztofik et al. (2020b), as increasing the number of repetitions led to higher time under tension. Based on this, future research should address whether a group performing a PAPE protocol combined with a moderate velocity loss (i.e., 20% of velocity loss) can complete more repetitions than a control group for several sets (four to six sets). Furthermore, if the PAPE experimental condition group can perform more repetitions, it would be interesting to carry out a long-term intervention to examine whether this protocol would bring more muscle mass gain than a control condition.

This study faced several limitations, including a relatively small (n = 12) sample size, which makes it difficult to generalise the obtained results. Our results prove that a PAPE protocol can be useful to improve performance in a task to failure, which makes PAPE a potential strategy to increase muscle hypertrophy gains. However, this was not measured, and therefore, further studies are warranted. Furthermore, our study included only one set until volitional failure, however, the effect of this set on performance in subsequent sets was not evaluated.

Conclusions

In conclusion, the results of this study suggest that a traditional PAPE protocol consisting of a single set of a single high intensity repetition (93% 1RM) improves bench press performance, measured as the number of repetitions completed until volitional failure. This could be due to psychological (Szalma and Hancock, 2011) or training specificity reasons (Behm and Sale, 1993). Also, performing a traditional PAPE augments velocity loss from the start of the set until the end, due to a greater capacity to perform slower last repetitions.

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Informed Consent: Informed consent was obtained from all participants included in the study

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Congress Presentation

Oral presentation:

Efectos de las contracciones isométricas voluntarias intermitentes en el rendimiento y la cinemática de la región de estancamiento en el press de banca

X Jornadas Internacionales de la Sociedad Española de Medicina del Deporte (Badajoz, Spain); From 25/11/2022 to 26/11/2022

X JORNADAS INTERNACIONALES de MEDICINA del DEPORTE

SOCIEDAD ESPAÑOLA de MEDICINA del DEPORTE

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25-26 de noviembre de 2022

El Comité Organizador de las

X JORNADAS INTERNACIONALES DE LA

SOCIEDAD ESPAÑOLA DE MEDICINA DEL DEPORTE

CERTIFICA QUE

la Comunicación Científica titulada

EFECTOS DE LAS CONTRACCIONES ISOMÉTRICAS VOLUNTARIAS INTERMITENTES EN EL RENDIMIENTO Y LA CINEMÁTICA DE LA REGIÓN DE ESTANCAMIENTO EN EL PRESS DE BANCA

cuyos autores son

Garbisu-Hualde A, Gutierrez L, Fernández-Peña E & Santos-Concejero J.

ha sido presentada en las sesiones científicas celebradas los días 25 y 26 de noviembre de 2022 en su sede de la Universidad de Extremadura.

Miguel Valle

El Presidente del Comité Organizador
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Other Contributions

External reviewer for a study on the topic for the *Research Quarterly for Exercise and Sport*

External reviewer for a study on the topic for the *Journal of Human Kinetics*

Peer Review for Research Quarterly for Exercise and Sport

MM Matthew Miller <mwm0024@auburn.edu>
Para agarbisu002@ehu.eus

martes, 28 de marzo de 2023, 15:04

Dear Dr. Garbisu-Hualde,

I am writing in my role as an associate editor for *Research Quarterly for Exercise and Sport* where I am seeking reviewers for a manuscript that was influenced by and related to your research. The title of the manuscript is "[redacted]" I would be very grateful if you agree to review this manuscript, in which case I will have a formal invitation sent. The journal typically gives reviewers about a month to complete the review, but I can look into an extension if you are interested in the manuscript but are crunched for time at the moment. Additionally, if you know anyone else who would be a good reviewer, please let me know, irrespective of whether you agree to the review.

Thank you for considering the review!

Matt

Matt Miller, Ph. D. (he/him)
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Review of the manuscript number [redacted]

Journal of Human Kinetics <kontakt@editorialsystem.com>
Hoy a las 9:11
Para Arkaitz Garbisu-Hualde

Dear Mr. Garbisu-Hualde,

Thank you for accepting the review invitation concerning the manuscript entitled: [redacted]

Please note the review deadline: 2023-07-28

View article:
[redacted]

Review form:
[redacted]

Kindest regards,
Dr. Michał Krzysztofik
Section Editor
Journal of Human Kinetics

Ethics

approval

GIZAKIEKIN ETA HAUEN LAGIN ETA DATUEKIN EGINDAKO IKERKETEI BURUZKO ETIKA BATZORDEAREN (GIEB-UPV/EHU) TXOSTENA

Mª Jesús Marcos Muñoz andreak, Universidad del País Vasco/Euskal Herriko Unibertsitateko (UPV/EHU) GIEBeko idazkari gisa,

ZIURTATZEN DU

Ezen gizakiekin egindako ikerkuntzaren etika batzorde honek, GIEB-UPV/EHU, (2014/2/17ko 32. EHAA)
Balioetsi duela ondoko ikertzailearen proposamen hau:
Jordan Santos Concejero andreak, M10_2019_236, honako ikerketa proiektu hau egiteko:
"Efectos de diferentes protocolos de potenciación post activación en el rendimiento de sujetos físicamente activos"

Eta aintzat hartuta ezen

1. Ikerketa justifikatuta dago, bere helburuei esker jakintza areagotu eta gizarteari onura ekarriko baitio, ikerlanak lekartzakeen eragozpen eta arriskuak arrazoizko izanik.
2. Ikertzaile taldearen gaitasuna eta erabilgarri dituzten baliabideak aproposak dira proiektua gauzatzeko.
3. Ikerketaren planteamendua bat dator era honetako ikerkuntza egin ahal izateko baldintza metodologiko eta etikoekin, ikerkuntza zientifikoaren praktika egokien irizpideei jarraiki.
4. Indarreko arauak betetzen ditu, ikerketa egin ahal izateko baimenak, akordioak edo hitzarmenak barne.

Aldeko Txostena eman du 2019ko urriaren 17an egin duen bileran (117/2019akta) aipatutako ikerketa proiektua ondoko ikertzaileek osatutako taldeak egin dezan:

Jordan Santos Concejero
Arkaitz Garbisu Hualde

Eta halaxe sinatu du Leioan, 2019ko azaroaren 12an

INFORME DEL COMITÉ DE ÉTICA PARA LAS INVESTIGACIONES CON SERES HUMANOS, SUS MUESTRAS Y SUS DATOS (CEISH-UPV/EHU)

Mª Jesús Marcos Muñoz como Secretaria del CEISH de la Universidad del País Vasco/Euskal Herriko Unibertsitatea (UPV/EHU)

CERTIFICA

Que este Comité de Ética para la Investigación con Seres Humanos, CEISH-UPV/EHU, BOPV 32, 17/2/2014,
Ha evaluado la propuesta del investigador:
D. Jordan Santos Concejero, M10_2019_236, para la realización del proyecto de investigación: *"Efectos de diferentes protocolos de potenciación post activación en el rendimiento de sujetos físicamente activos"*

Y considerando que,

1. La investigación está justificada porque sus objetivos permitirán generar un aumento del conocimiento y un beneficio para la sociedad que hace asumibles las molestias y riesgos previsibles.
2. La capacidad del equipo investigador y los recursos disponibles son los adecuados para realizarla.
3. Se plantea según los requisitos metodológicos y éticos necesarios para su ejecución, según los criterios de buenas prácticas de la investigación científica.
4. Se cumple la normativa vigente, incluidas las autorizaciones, acuerdos o convenios necesarios para llevarla a cabo.

Ha emitido en la reunión celebrada el 17 de octubre de 2019 (acta 117/2019), **INFORME FAVORABLE** a que dicho proyecto de investigación sea realizado, por el equipo investigador:

Jordan Santos Concejero
Arkaitz Garbisu Hualde

Lo que firmo en Leioa, a 12 de noviembre de 2019

MARIA JESUS MARCOS MUÑOZ

Firmado digitalmente por MARIA JESUS MARCOS MUÑOZ
Fecha: 2019.11.12 08:40:58 +01'00'

GIEB-UPV/EHUko idazkari teknikoa
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