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Effects of post-activation potentiation on sprint swimming performance

Efecto de la potenciación post-activación en el rendimiento del nadador velocista

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- Cuenca-Fernández F, Smith IC, Jordan MJ, MacIntosh BR, Lopez-Contreras G, Arellano R, Herzoz W. (2017). Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: a pilot study. Appl Physiol, Nutr Metab.;42(10):1122-5. doi: 10.1139/apnm-2017-0217. PubMed PMID: 28675792. (Impact Factor: 2.02, Journal ranking: 2nd Quartil, Sport Sciences).

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- Cuenca-Fernández F, Curtis-Smith I, Arellano R. (2017) Squat jump and jumping push-up performance of trained swimmers inmediately before and after resistance exercise. Presented at the 11th World Congress of Performance Analysis of Sport, Alicante, Spain. Book of Abstracts published at the Journal of Human Sport and Exercise. 2017, 12(3proc): S908-S1143. Doi:10.14198/jhse.2017.12.Proc3.14

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- Szczepan S, Cuenca-Fernández F, Gay A, Arellano R (2018) The effects of concurrent visual versus verbal feedback on swimming-specific task execution. Submitted to Human Movement in February 2018. (Cite Score: 0.41).

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ABBREVIATIONS INDEX

Post-activation potentiation	PAP
Swimming start	SS
Conditioning activity	CA
Post-activation performance enhancement	PAPE
Repetition maximum	RM
Regulatory Light Chain	RLC
Squat Jump	SJ
Power push-up	PPU
Quiet standing	QS
Back squat	BS
Bench press	BP
Standard deviation	SD
Ground Reaction Forces	GRF
Hertz	Hz
Time of jump initiation	T_i
Time of take-off	T_o
Body weight	m
Aceleration due gravitiy on Earth	g
Calcium release by the sarcoplasmatic reticulum	Ca^{2+}
Basic muscle evaluation	BME
Conditioning exercise	CE
Conditioning exercise on lower limbs	CE-L
Conditioning exercise on upper limbs	CE-U
Conditioning exercise both in lower and upper limbs	CE-UL
Bilateral surface electromyography	EMG
Decibels	Db
Rectus Femoris	RF
Vastuls Lateralis	VL
Pectoralis Major	PM
Triceps Brachii	TB
Standard warm-up	SWU
Lunge warm-up	LWU
YoYo warm-up	YWU
Dive distance	DD

Flight time	FT
Velocity of the hip at flight	VxH
Time to 5 – time to 50	T5–T50
Angle of take-off	AT
Angle of entry	AE
Angular velocity of the knee at extension	VϖK
High Speed	HS
Intraclass correlation coefficient	ICC
Relative Force	F_{REL}
International Swimming Federation	FINA
Reaction time	RT
Movement time	MT
Block time	BT
Average force	AvF
Peak force	PeF
Impulse	I
Resultant vector	Res
Velocity	Vel
Average acceleration	AvAccel
Peak acceleration	PeAccel
Average power	Av_{POWER}
Peak power	Pe_{POWER}
Resultant power	Res_{POWER}
Rate of force development	RFD
Repetition maximum warm-up	RMWU
Eccentric warm-up	EWU
Centigrade Celsius	ºC
Diving velocity	DV
Underwater undulatory swimming	UUS
Velocity to 5 m – velocity to 50 m	V5-V50
Stroke rate	SR
Stroke length	SL
Isolated swimming phase	ISP

ABSTRACT OF THE THESIS

ABSTRACT OF THE THESIS

Introduction: In sprint swimming, every instant is critical. Nowadays, is common to see how sprint swimmers prepare for racing by activating themselves on many different ways such as doing ballistic stretching, by increasing their breathing and heart rate, or by strongly clapping their chest or limbs. Whether or not those methods really have an influence is not part of this study. However, it cannot be rejected the fact that sprint swimmers need to create an extra activation on their system in order to race at the best of their capacities. Therefore, a suitable activation protocol able of stimulating the neuromuscular system in the best conditions is needed. Many of those methods have been based on post-activation potentiation (PAP). A procedure which improves muscle contractily both in strength and speed through previously applying maximal o submaximal conditioning exercises on the muscle system. The aim of this thesis was testing different PAP protocols on sprint swimming performance. ***Methods:*** 6 protocols testing different PAP applications were applied on trained swimmers. In total, 60 different swimmers participated on this thesis. First, it was assessed the influence of conditioning exercises on producing non-localized presence of PAP on lower limbs by testing two maximal voluntary contractions (squat jump and power push-up) on a force plate. Subsequently, same procedures were studied testing different rest time administration between conditioning exercise and test. Upper limbs assessment through force plate and bilateral surface electromyography (EMG) was also adhered in the study. On the other hand, in order to obtain results related to specific swimming-movements, PAP methods were extrapolated from experimental conditions and tested on a swimming start performance. Free-weight load lifting and maximal eccentric flywheel contractions simulating the movement of a swimming start were tested. Kinetic and kinematic variables of performance were obtained through a dynamometer experimental block start station and by photogrammetry. Individual's strength index were also discussed and related to the results. Finally, conditioning exercises simulating arm strokes in swimming through free-weight and eccentric flywheel were tested on the variables of competition of a swimming race. ***Results:*** It was found that assessing pre-daily performance is important as might condition the magnitude and likelihood of finding PAP. Furthermore, possibly callisthenics are able of stimulating the neuromuscular system and it produces similar potentiation effects on performance. Swimming starts are able of being improved through PAP as velocity at take-off was higher, specially after eccentric warm-up protocols. This improvements would come from improvements on the vertical vectors of force/impulse developed by the lower limbs on the block. In fact, stronger athletes seem to react better to PAP protocols, possibly because myosin phosphorilation (main PAP precursor) is more frequent on type II fibers. The first meters of a swimming race might be improved by using

PAP. However, some swimming patterns as stroke length might be deteriorated along the race. ***Conclussion:*** Fatigue and potentiation co-exists as responses of PAP, therefore, it generates very individualized responses, specially in males. As the application of this methods to competitive constraints seem unfeasiable, this thesis also proved that callisthenics may also produce similar results. Positive results might be obtained from applying PAP methods on the swimming start impulse although is still needed finding a suitable intensity for the conditioning exercises applied on upper limbs.

RESUMEN DE LA TESIS

RESUMEN DE LA TESIS

Introducción: En las pruebas de velocidad de natación cada instante es crítico. Hoy en día, es común ver cómo los velocistas se preparan para las carreras activándose de maneras muy diferentes y variadas. Fuertes palmetazos en las extremidades, movimientos acelerados y estiramientos balísticos de brazos y piernas y/o hiperventilación para aumentar la frecuencia cardiaca y respiratoria son frecuentes instantes antes a una prueba. Si estos métodos realmente influyen o no, no es parte de este estudio. Sin embargo, no se puede rechazar el hecho de que los nadadores de velocidad necesitan crear una activación adicional en su sistema para competir al máximo de sus capacidades. Por lo tanto, se necesita un protocolo de activación adecuado capaz de estimular el sistema neuromuscular en las mejores condiciones. Muchos de esos métodos se han basado en la potenciación post-activación (PAP). Un procedimiento que mejora la contractilidad muscular tanto en fuerza como en velocidad aplicando previamente ejercicios de acondicionamiento máximo o submáximo en el sistema muscular. El objetivo de esta tesis fue probar diferentes protocolos PAP sobre el rendimiento de natación sprint. ***Métodos:*** Se realizaron un total de 6 protocolos que probaron diferentes aplicaciones de PAP en nadadores entrenados. En total, unos 60 nadadores diferentes participaron en esta tesis. En primer lugar, se evaluó la influencia de los ejercicios de acondicionamiento para producir PAP no localizado en las extremidades inferiores mediante la realización de dos contracciones voluntarias máximas (salto desde sentadilla y flexiones con salto) en una plataforma de fuerzas. Posteriormente, se estudiaron los mismos procedimientos para evaluar la administración de diferentes tiempos de descanso entre el ejercicio de acondicionamiento y el test. A este studio también se adhirió la evaluación de las extremidades superiores a través de la plataforma de fuerzas y electromiografía (EMG). Por otro lado, para obtener resultados relacionados con movimientos específicos de natación, algunos métodos de PAP se extrapolaron de las condiciones experimentales y se evaluaron en gestos específicos de la natación. Para evaluar el efecto del PAP en la salida de natación se utilizaron dos ejercicios de acondicionamiento tratando de imitar el movimiento de flexo-extensión que se realiza en el poyete de salida. Estos ejercicios consistieron en dos zancadas, una realizada con peso libre y otra realizada en una máquina inercial de contracción excéntrica. A través de un bloque experimental capaz de evaluar las fuerzas generadas por el nadador en el impulso y mediante fotogrametría, se evaluaron las variables cinéticas y cinemáticas del rendimiento, respectivamente. El índice de fuerza de los nadadores también se discutió y se relacionó con los resultados. Finalmente, también se evaluaron ejercicios de acondicionamiento que simulaban las brazadas en natación sobre las variables de competición de una prueba de natación. ***Resultados:*** Evaluar el rendimiento diario en el momento de realizar el pre test es importante ya que podría condicionar la probabilidad y magnitud de encontrar PAP. Además, posiblemente los ejercicios calisténicos son capaces de estimular el sistema neuromuscular y de producir efectos de potenciación similares al PAP. Las salidas de natación son susceptible a ser mejoradas a través de protocolos de PAP ya que la velocidad en el despegue fue mayor, especialmente cuando se aplicó la estimulación excéntrica. Estas mejoras vendrían de las mejoras en los vectores verticales de fuerza desarrollados por las extremidades inferiores en el poyete. De hecho, los atletas más fuertes parecen reaccionar mejor a los protocolos de PAP, posiblemente porque la fosforilación de la miosina (principal agente regulador del PAP), es más frecuente en las fibras de tipo II. Los primeros metros de una prueba de 50 metros podrían mejorarse utilizando PAP. Sin embargo, algunos patrones técnicos de eficiencia en natación como la longitud de la brazada podrían deteriorarse a lo largo de la prueba. ***Conclusión:*** La fatiga y la potenciación coexisten como respuestas del PAP, por lo tanto, esto genera respuestas muy individualizadas en función del nivel o del estado físico del atleta, especialmente en los varones. En la salida de natación se pueden obtener resultados positivos tras aplicar protocolos de PAP en el calentamiento. Sin embargo, todavía es necesario encontrar una intensidad o un period de descanso más adecuado para los ejercicios de acondicionamiento aplicados en las extremidades superiores.Como la aplicación de estos métodos en competición parece dificil, esta tesis también demostró que la calistenia también puede producir resultados similares sin la necesidad de utilizar un equipamiento tan específico.

El éxito es constancia, sacrificio, trabajo duro y sobre todo, pasión por lo que se hace.

El éxito no es un accidente.

CHAPTER I

- AIMS OF THIS THESIS
- OBJETIVOS DE LA TESIS

AIMS OF THIS THESIS

- To study the basics of post-activation potentiation (PAP) and its previous applications in swimming according the existent literature.

- To assess the effects of different PAP application both in lower and upper limbs and see the presence of localized/systemic effects on lower limbs.

- To test PAP warm up protocols both in lower and upper limbs and see the effects produced on performance collected through maximal voluntary efforts as vertical jump and jumping push ups.

- To test PAP warm up protocols both in lower and upper limbs applying different rest times between the conditioning exercise and the test.

- To test the application of two specific PAP warm-up protocols on performance on a swimming start.

- To obtain a relation between performance on lower limbs assessed through dry-land tests and results obtained on the water through a swimming start performance.

- To understand how PAP affects the propelling forces acting on a swimming start block performed by the swimmer.

- To analyze the application of two specific PAP warm-up protocols on performance on a sprint swimming race (50-m).

- To understand how PAP affects the swimming patterns of the swimmers while perform a sprint swimming race (50-m)

- To obtain a relation between performances on upper limbs assessed through dry-land tests and the results obtained on the water performing a sprint swim race (50-m).

OBJETIVOS DE ESTA TESIS

- Estudiar los fundamentos de la potenciación post-activación (PAP) y sus aplicaciones previas en la natación atendiendo a la literatura existente.

- Evaluar los efectos de diferentes aplicaciones de PAP en los miembros inferiores y superiores y ver la presencia de efectos localizados o sistemáticos en las extremidades inferiores.

- Probar los protocolos de precalentamiento de PAP tanto en las extremidades inferiores como en las superiores y ver los efectos producidos en el rendimiento recogidos a través de acciones voluntarias máximas como el salto vertical y las flexiones con salto.

- Probar los protocolos de precalentamiento de PAP tanto en las extremidades inferiores como en las superiores aplicando diferentes tiempos de descanso entre el ejercicio de acondicionamiento y la prueba.

- Probar la aplicación de dos protocolos de precalentamiento específico basados en PAP sobre el rendimiento en una salida de natación.

- Obtener una relación entre el rendimiento en las extremidades inferiores evaluadas mediante test en seco y los resultados obtenidos en el agua a través de una salida de natación.

- Comprender cómo el PAP afecta a las fuerzas de propulsión que el nadador aplica en un poyete de salida de natación.

- Analizar la aplicación de dos protocolos específicos de precalentamiento basados en PAP sobre el rendimiento en una prueba de natación de velocidad (50 m).

- Comprender cómo el PAP afecta los patrones técnicos de natación en una carrera de natación de velocidad (50 m)

- Obtener una relación entre el rendimiento de los miembros superiores evaluado a través de pruebas en seco y los resultados obtenidos en el agua en una prueba de velocidad (50 m).

CHAPTER II

- INTRODUCTION TO PAP
- PAP IN SWIMMING STARTS
- PAP IN SPRINT SWIMMING PERFORMANCE

INTRODUCTION TO POST-ACTIVATION POTENTIATION

Winning or losing in high performance sports is often determined by a fraction of a percent difference in performance. For decades now, athletes, coaches and scientists have attempted to prepare athletes to the best of their abilities for competitions. One aspect of such preparation involves the warm-up that immediately precedes a competition. It has been argued anecdotally that the activities performed in the 5-15 minutes immediately prior to competition might crucially affect muscle performance. Specifically, brief, high-force contractions of muscles have been implicated in acute elevations in muscular performance [13, 27]. Whether such performance enhancement truly exists and the causes of acute muscular performance enhancement remain disputed and unclear.

The most obvious effect of contractile history is fatigue, which impairs performance [10, 12, 31]. There are possible sites of neuromuscular fatigue that would affect force production capabilities. Central fatigue mechanisms, such as suboptimal cortical drive and changes in afferent input have been reported in the literature [31]. On the other hand, peripheral fatigue could be related to impairment of enzyme activity through local acidosis, or may be due to the impaired excitation-contraction coupling through changes in action potential propagation or calcium release. However, it is known that when an action induces acute fatigue, it may be followed by a period of potentiated force production capability, termed as Post-activation Potentiation (denoted PAP) [26]. A possible mechanism underlying an enhancement of muscle performance could be the phosphorylation of the myosin light chains [4, 14], specifically, when a muscle is fatigued at high load and a low frequency, cells fibers become more sensitive to the calcium concentration, enhancing cross-bridge attachment and subsequently generating greater force compared to the prior (resting) condition. Fatigue and potentiation co-exist as responses following muscle and motor unit activation, thus the performance enhancement depends on the prevalence of PAP over fatigue [3, 8, 23, 26]. Such relationship has been argued as the reason behind the improvement of the individuals with higher level of conditioning. Because the myosin phosphorylation is more present in type II fibers [15].

The term postactivation potentiation (PAP) classically refers to the enhancements electrically evoked twitch force [6, 29]. This definition has not been strictly adhered to, with several papers purportedly studying PAP having only measured enhancements of voluntary activations. However, it is worth noting that twitch verification is also an indirect surrogate of the effect of actin-myosin phosphorylation on muscle force production [14], generating also an increase in the number of cross-bridges formed and consequently a temporary increase in the rate of force development [20]. These facts are able to be measured through maximal voluntary contractions, therefore, assuming the limitation that a true PAP effect could be solely verified with the twitch interpolation technique, in the present study it will be measured by its effects on maximal voluntary contractions of swimming.

On the other hand, PAP can be explained by enhanced neural activation at the spinal cord. This includes an increasing in motor unit stimulation/recruitment, enhanced motor unit synchronization, and/or decreased presynaptic inhibition [8]. This increased drive in motor cortex is reflected in the Hoffman (H)-reflex amplitude, which is a measure between Ia afferents and homonymous α-motoneurons [11]. However, some studies have failed in associate such improved effects with a better performance, maybe because if wanting to provoke a neuromuscular activation by voluntary contractions, some attributes of tetanic electrical stimulation are required to produce the potentiation of the H-reflex, such as a high proportion of fast units, a maximum stimulus intensity (≥ 100%) and considerable stimulus duration (several seconds) [3, 15, 31]. All factors who presumably could provoke a high level of fatigue, and who added to an unchanged M-wave peak to peak amplitude during PAP, and a comparable potentiation for tetanic and voluntary contractions mainly would relate PAP with the intramuscular physiological mechanisms [4, 5].

PAP benefits are more effective if an optimal recovery time is given after the conditioning activity, because the optimum performance occurs when the fatigue has dissipated and the enhancement still exists [24, 28]. This balance between PAP and fatigue and its effect on subsequent activity was explained by Tillin & Bishop (2009)[28] according to the general model of relationship between PAP/Fatigue following a pre-conditioning contraction initially proposed by Sale (2004)[24], (Figure 2.1).

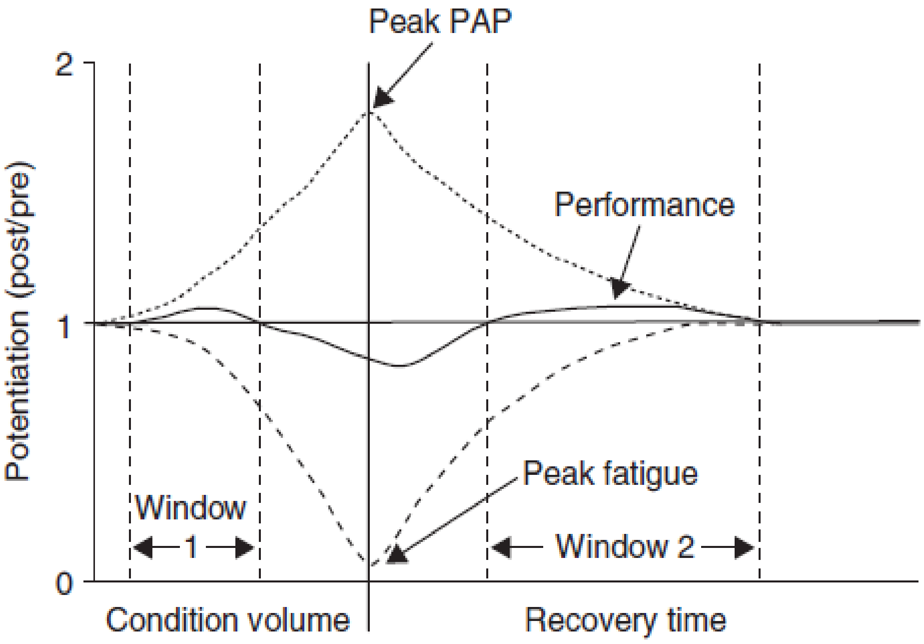

Figure 2.1 A model of the hypothetical relationship between postactivation potentiation (PAP) and fatigue following a pre-conditioning contraction protocol. Taken from Tillin & Bishop (2009)[28].

In spite of PAP is immediately present after a muscle contraction, fatigue is present early on. Furthermore, fatigue seems more dominant in the early stages of recovery and, consequently, performance of subsequent voluntary activity is diminished or unchanged. Nevertheless, fatigue subsides at a faster rate than PAP, and potentiation of performance can be realized at some point during the recovery period, amplifying the muscle action potential and consequently the athletic performance [28].

PAP IN SWIMMING START:

Traditionally, authors have attempted to improve performance on swimming starts stablishing the effectiveness of resistance training programmes designed to improve the lower body strength. For instance, Breed & Young (2003)[7], tested the effects of resistance training on vertical jumping ability, on the grab, swing and rear-weighted track starts in swimming. Analysis revealed that resistance training improved performance in the dry-land tests (countermovement jump, isokinetic squats and overhead throws). However, no significant improvements due to training were found for any temporal, kinematic or kinetic variables withing the grab or swing starts. Improvements only were obtained for the track start for take-off velocity, take-off angle and horizontal impulse. The authors concluded that improved skill of vertical jumping was not directly transferred to the start, particularly in the grab technique and claim for the necessity of practising the dives to retain the changed neuromuscular properties. On the other hand, Podtevin et al., (2011)[22], obtained positive effects on dryland tests related with jumping and concluded that specific swimming tasks such as dive and turn might benefit after applying 6-weeks of plyometric training. However, performance on a swimming start was no directly tested and results were not very conclusive.

If considering the intrinsic basics found in every training programme designed to improve the capacities or performance of a group of athletes, the systematic application and stimulus administration in PAP does not differ from a traditional training protocol. Commonly, a training protocol may include various weeks of stimulus administration (practice), in order of producing both physiological as neurological adaptations on the system [19]. However, if wanting to avoid persistent performance incompetence and high fatigue ratings with the purpose of obtaining a super-compensation in performance, athletes should take some rest days either every week or right before a competition [19]. Considering the administration of PAP methods, the same general structure is followed; a conditioning activity is applied to produce an stimulus and then a period of rest is given for obtaining a super-compensation in performance. Nevertheless, a remarkable difference on time is identified on every of the steps of the process (Figure 2.2).

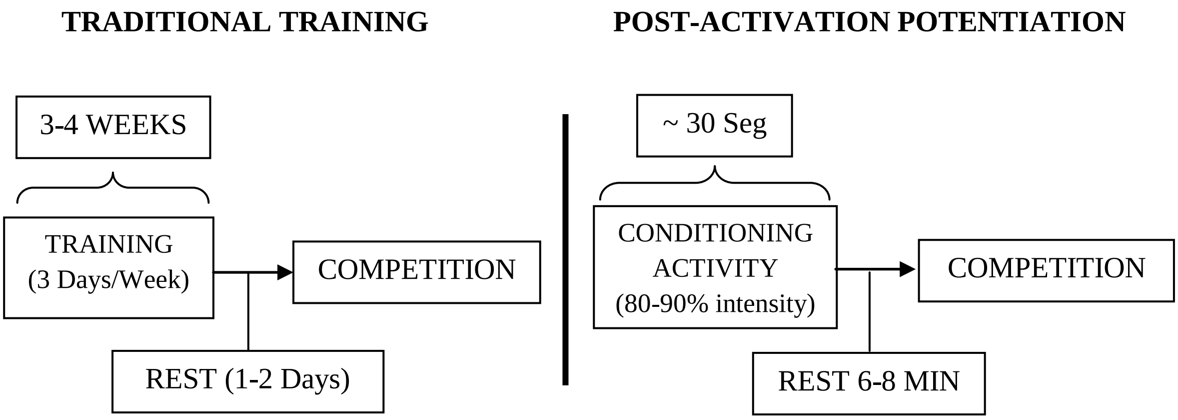

Figure 2.2. Comparison between training protocol applications (left) with a post-activation protocol application (right).

Sports modalities related with jumping, sprinting or explosive gestures as throwing, have always obtained better outcomes than others more related with endurance or cyclic sports, in the recent PAP literature [27]. This might have conditioned that first studies testing this effect on swimming were focused on swimming start performance. In 2011, one study carried out by Kilduff et al. (2011)[18] was the first in testing PAP in swimming. Traditional swimming warm up was substituted by an experimental protocol based on 3 maximal back squat repetitions at 87% of 1RM. Swimmers were then tested in a swimming start by using a force plate placed on the swimming block. Results on time at 15m mark did not reveal any improvement, but a worsening on performance was either detected. On the other hand, force plate outcomes revealed that peak forces exerted on the block were indeed augmented after such experimental warm up; therefore authors suggested that swimmers could find benefits from these methods and claimed for future research which added this kind of protocols in their warm up routines.

PAP IN SPRINT SWIMMING PERFORMANCE

Any increase in swimming velocity requires a proportional increase in the applied muscle force and the development of power, capacity and efficiency in the energy delivery systems to sustain a higher swimming velocity [30]. Muscles provide work and power to effect movement through contractions, which are characterized by the production of force and changes in length over a discrete time interval, suggesting the existence of strong logical relationships between strength abilities and performance in swimmers [21]. One of the principles of PAP is providing a conditioning exercise that is as similar as possible to the real action [27]. Therefore, if the movement of the body is the outcome of a carefully sequenced activation of motor units to provide the force and displacement required for limb articulation [9, 14], identification of an approach for stimulating the motor units needed for the task under the optimal conditions is necessary.

Through the use of PAP-based methods, controversial results have been obtained in sprint swimming performance. One of the first studies examined the effects of two conditioning exercises on 25-m freestyle swimming; resisted crawl swimming at 30% of the 1 RM in a power rack; and freestyle arm strokes with elastic bands. However no differences were found between group [17]. In contrast, the same swimming warm-up was attempted in a subsequent study [16], but PAP was tried through four maximal 10-m swims at 1-min intervals while attached to a resistive power rack in a group of 30 collegiate swimmers (15 men, 15 women). On this case, PAP-based warm up yielded positive results in a 100-m freestyle race and the researchers concluded that six min of rest was sufficient for recovering from the conditioning activity and performing the task. Another study attempted to obtain PAP benefits by using paddles and a parachute while performing short bouts of maximal sprint swimming [2]. Unfortunately, the results did not reveal any differences. The low intensity of the conditioning exercises applied or, an inconsistent application of the rest time between trials might be responsible for the lack of significance obtained in the aforementioned studies [28].

One of the first studies in providing optimistic outcomes compared different types of resistance warm-ups for national-level swimmers competing in a 50-m freestyle race [25]. The warm-ups consisted of the traditional race-specific warm-up, upper-body PAP induced by maximal pull-ups, lower-body PAP induced by loaded counter-movement jumps, and combined PAP warm-up. The results showed that the protocols involving PAP did not offer better performance and the race-specific warm-up showed better results than the experimental protocols ($p = 0.046$). Nevertheless, grouping the results into gender revealed that the males who underwent the upper-body warm-up ($p = 0.047$) and the combined PAP warm-up ($p = 0.02$) showed better performance, indicating a high individualization of PAP application particularly in males [20], or in individuals with high proportion of fast fibers [24]. Therefore, considering that actin-myosin phosphorylation is more present in type II fibers and stimulation of this type of fibers is only possible when a muscle contraction is performed at maximal intensity [4], a relationship between high intensity resistance exercises as a method of conditioning and higher PAP effects might be discerned from these results.

CONCLUSIONS:

To date, there are few studies that examined the swimming start performance using different types of warm-up, and those that exist, are conducted with a lack of specific stimulus for the lower limbs or upper limbs of the subjects [1, 7, 18]. Moreover, to author’s knowledge, there is any study where this issue is assessed on the new block, where the legs have an asymmetric placement. PAP effects have been studied in jumping and sprint running for a long time, but few studies investigated it in sprint swimming where sprint swimmers need to be really well physically activated to release all its power in a short amount of time. Therefore, the question we are aiming to answer is indeed highly relevant to swimming competition performance and as such deserves to be investigated.

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CHAPTER III

- NONLOCALIZED POSTACTIVATION PERFORMANCE ENHANCEMENT EFFECTS IN TRAINED ATHLETES: A PILOT STUDY

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ABSTRACT

Introduction: Intense muscle contraction (conditioning activity; CA) is widely purported to improve the performance of powerful voluntary movements which follow soon after. This postactivation performance enhancement (PAPE) is an important consideration for pre-competition warm-up of elite athletes. However, a definitive physiological explanation for PAPE is lacking. This study was designed to test the assumption that PAPE can only occur when the CA and test movement activate the same muscles. ***Methods:*** In this study, we assessed the impulse generated during squat jumps performed by trained swimmers (8 males, 7 females) before (Pre) and after (Post) four different CAs using a randomized repeated measures study design. The CAs included 1) 4 minutes rest, 2) 4 repetitions of back squat at 90% of the swimmers' one repetition maximum load (1RM), 3) 4 repetitions of bench press at 90% 1RM, and 4) 4 repetitions each of bench press and back squat at 90% 1RM. ***Results:*** PAPE was seen at 5 min Post, with improvements ($P<0.05$) over Pre between 0.6 and 2.4% after each of the four CAs. The maximum PAPE achieved at any Post time point in each of the four CAs ranged between 2.1 and 4.8% increases ($P<0.05$) over Pre. PAPE did not differ between the different CAs. ***Conclusion:*** PAPE effects were obtained after specific CE. However, the improvements seen on the no specific conditioning protocols suggested that the squat jump used as a test protocol is capable of producing a PAPE effect on its own. Since this protocol activated both upper and lower limb musculature, the existence of a non-localized PAPE effect remains a possibility in need of future study.

KEY WORDS: Squat jump, post-activation potentiation, voluntary contractions, muscle function, swimming

RESUMEN

Introducción: las contracciones musculares intensas (actividad de acondicionamiento, CA) son frecuentemente utilizadas para mejorar el rendimiento de los ejercicios explosivos realizados justo después, de forma voluntaria. Esta mejora del rendimiento en actividades realizadas de forma voluntaria (efecto PAPE), es una consideración importante para el calentamiento previo a la competición de los atletas de élite. Sin embargo, falta una explicación fisiológica definitiva para este efecto. Este estudio fue diseñado para probar la suposición de que el PAPE solo puede ocurrir cuando la CA activa los mismos músculos que se utilizan para realizar la prueba o el test. ***Método***: en este estudio, evaluamos el impulso generado durante los saltos desde la media sentadilla, realizados por nadadores entrenados (8 hombres, 7 mujeres) antes (Pre) y después (Post) de cuatro CA diferentes usando un diseño de estudio de medidas repetidas aleatorizadas. Las CA incluyeron 1) 4 minutos de descanso, 2) 4 repeticiones de sentadilla al 90% de la carga maxima (1RM), 3) 4 repeticiones de press de banca al 90% 1RM y 4) 4 repeticiones cada una de press de banca y sentadilla con la espalda al 90% 1RM. ***Resultados:*** se observó PAPE en el Post-test realizado a los 5 minutos, con mejoras (P <0.05) sobre Pre entre 0.6 y 2.4% después de cada una de las cuatro CA. El PAPE máximo alcanzado en cualquiera de los Post-tests en cada una de las cuatro CA varió entre 2.1 y 4.8% de incremento (P <0.05) sobre Pre. El PAPE no difirió entre las diferentes CA. ***Conclusión:*** Los protocolos de PAP fueron capaces de mejorar el rendimiento. Sin embargo, las mejoras obtenidas en los protocolos en los que no se aplicaron cargas específicas en las extremidades inferiores nos sugiere que los test utilizados para medir el rendimiento (saltos desde la media sentadilla) también fueron capaz de producir un efecto PAPE por sí mismo. Por tanto, dado que este protocolo activó la musculatura de las extremidades superiores e inferiores, la existencia de un efecto de PAPE no localizado sigue siendo una posibilidad que necesita estudio futuro.

INTRODUCTION

The athletic community has shown considerable interest in the performance enhancements seen soon after a warm-up of brief, high force contractions (conditioning activity; CA)[14]. The magnitude and time history of the enhancement depends on whether performance is assessed in electrically evoked or voluntary contractions. Enhancements of electrically evoked contractions are typically large (>20%) increases in twitch torque during the first minute after the CA which decline over several minutes [16, 18]. In contrast, enhancements in voluntary movements are typically small (<5%) effects observable after a significant rest period, peaking 7-10 minutes after the CA [11, 16, 20], a time when there is effectively no remaining enhancement of electrically evoked contractions. The differences between these effects have been obscured by imprecise use of terminology in the literature. The term postactivation potentiation (PAP) classically refers to the enhancements electrically evoked twitch force [1, 19]. This definition has not been strictly adhered to, with several papers purportedly studying PAP having only measured enhancements of voluntary activations. In this study we refer to enhancements in electrically evoked contractions as PAP, and the enhancement of voluntary movements as postactivation performance enhancements (PAPE).

There is strong evidence that PAP is a local effect caused by contraction-induced increases in myosin regulatory light chain (RLC) phosphorylation [18, 19]. PAPE, however, could be achieved via a number of effects unrelated to RLC phosphorylation including increased muscle temperature [10, 12, 15], increased recruitment of motor units with high recruitment thresholds [16], and increased excitability or firing synchrony of motor neurons [6, 17, 18]. The inotropic effects of exercise-induced elevations in plasma catecholamines [3, 5], may also contribute to PAPE, but this has not been investigated in detail. Specifically, brief bouts of intense exercise can increase circulating epinephrine and norepinephrine levels [2]. Exposure to these catecholamines enhances force in both fast and slow muscle fibres [3]. As circulating hormones, norepinephrine and epinephrine could systemically enhance muscle contraction. A non-localized PAPE effect is an intriguing notion, however, we are not aware of any study which has tested for PAPE in muscle groups which were not activated by the CA. Such an effect would be of great interest to the sporting world as it could circumvent the detrimental effects of neuromuscular fatigue [13]. In this study we assessed squat jump (SJ) and power push-up (PPU) performance in trained swimmers before and after four different CAs: quiet standing (QS), back squat (BS), bench press (BP), and BS+BP. We hypothesized that there would be no

PAPE following QS, and chose the conservative hypothesis that PAPE effects would be purely local responses.

Materials and methods:

Subjects

Fifteen varsity level swimmers (8 males and 7 females) volunteered to participate in this study (mean ± SD, Age: 19.4 ± 1.4 years, Weight: 78.6 ± 9.0 kg [males], 65.4 ± 8.5 kg [females], Height: 1.83 ± 0.02 m [males], 1.64 ± 0.06 m [females]). Swimmers were in their competition period and had participated in national and international competitions for at least 1 year prior to the start of the study. The swimmers habitually trained 6 days per week using a complex training protocol which allowed the development of power and speed while decreasing the volume of aerobic training [8]. None of the swimmers were taking drugs, medication, or dietary supplements known to influence physical performance. Tests were scheduled to take place prior to their daily training regimen, and subjects were instructed to avoid any physical exertion prior to testing. Each test day began with participants standing quietly for 10 minutes. Test familiarization was performed during their dry practices held three times per week. During the familiarization period, the load required to perform a 1 repetition maximum (1RM) lift was determined for back squat and bench press according American College of Sports Medicine guidelines (Armstrong *et al.* 2006). The 1RM for back squat was 90.7 ± 17.0 kg for males and 53.1 ± 14.1 kg for females. The 1RM (mean ± SD) for bench press was 71.3 ± 12.2 kg for males and 34.1 ± 10.3 kg for females. All experiments were performed in the Olympic Oval at the University of Calgary. Subjects signed an informed consent form which was reviewed and approved by the Conjoint Health Research Ethics Board at the University of Calgary (REB 15-1135).

Experimental approach

A repeated measures counterbalanced design was used in which swimmers were evaluated for squat jump and power push-up performance before and after each of four different

CAs tested over four different days. One CA aimed to activate the muscles of the lower body using 4 repetitions of BS loaded at 90% of 1 RM. A second protocol aimed to activate the upper body with 4 repetitions of BP loaded at 90% of 1 RM. A third protocol aimed to activate both the upper and lower body with a combination of BP and BS, 4 repetitions of each at 90% 1RM. The fourth protocol served as a control condition in which participants were instructed to quietly stand (QS) for four minutes, equivalent to the time required to perform the BS and BP exercises. Squat jump and power push-up performances were assessed 4 minutes prior to (designated as Pre), and at 5 and 8 minutes following (designated as Post-5 and Post-8) the completion of each CA. This study was designed in accordance with the schematic guidelines established in MacIntosh *et al.*, (2012)[10] for determining the impact of warm-up activities on athletic performance.

To minimize elastic contributions to performance, subjects were required to perform a countermovement and then hold that position stable for 2 seconds prior to performing each task. Squat jumps were performed with both feet on the force plate at takeoff and landing, hands placed on the hips, and squat depth during the static hold was self-selected. The power push-ups were performed with the goal of pushing the upper body away from the ground with as much speed and power as possible, leaving the ground with arms extended. Both hands were on the force plate during the push off and the landing. The position during static hold was self-selected. Toes were to remain in contact with the ground at all times; six of the seven females in this study performed a modified power push-up in which their knees and toes maintained contact with the ground. An encouraging verbal signal was given as the start command for each ballistic movement. Performance was assessed from the ground reaction force (GRF) exerted on the force plate.

Impulse analysis

Muscle performance was inferred from the vertical impulse obtained from the GRF vs time recording from a force plate (PASCO®, PS-2141. Roseville, CA 95747 USA). Data were collected at 1000 Hz using DataStudio (version 1.9.8r10). Impulse was calculated according to Linthorne, (2001)[9] , using the impulse-momentum method shown in equation 1.

$$(1)\ \text{Jump Impulse} = \int_{t_I}^{t_{\mathrm{TO}}} (F_{\mathrm{GRF}} - m \cdot g) \cdot\ dt$$

Here, the impulse associated with the lower limb muscles is equal to the integration of the GRF-time record from the time of jump initiation (t_I) to time of take-off (t_{TO}) minus the integration of the product of body weight and the acceleration due gravity on earth, adjusted for elevation ($m \bullet g$; a constant value for each subject each test day) over this same time period. For practical considerations, the $m \bullet g$ term was determined from the GRF during a period of quiet standing each collection day. The t_I was defined as the final instant at which the GRF dropped below $m \bullet g$. If t_I could not be defined in the 1 s prior to the jump, t_I was set to the time of lowest F_{GRF} in the 1 s prior to the jump if F_{GRF} exceeded $m \bullet g$, or the time of highest F_{GRF} in the 1 s prior to the jump if F_{GRF} was lower than $m \bullet g$ during this 1 s period. This analysis method was chosen to minimize the influence of any undesired countermovement immediately preceding the jump. The t_{TO} was defined as the time the GRF reached zero during the jump.

Statistical analysis

Statistical analysis was performed using Statistica 7.0 (Statsoft, Tulsa, Oklahoma, USA). After testing for normality of distribution, 2-way (time x condition) repeated measures ANOVAs were used to compare impulse in the lower limbs at Pre-Post time points. Tukey's honest significant difference (HSD) post hoc test was used to obtain specific comparisons when warranted. Differences were considered significant at $\alpha < 0.05$. Unless otherwise specified, all values are reported as mean ± SD. Males and females were grouped together in all analyses.

RESULTS

The coefficient of variation in SJ performance across all Pre trials was 0.060. There were no significant systematic differences in best jump performance at Pre between days (Figure 3.1A). Post hoc testing revealed a significant increase ($P<0.05$) in jump impulse at Post-5 relative to Pre (Figure 3.1B). Post-Max was significantly greater ($P<0.05$) than Pre as a main effect of a 2 way repeated measures ANOVA (not depicted). The percent change in impulse between Pre and Post-5 and between Pre and Post-Max were compared across the four CAs

(Figure 3.1C) using 1 way repeated measures ANOVAs. In these analyses, no statistically significant differences were seen. To determine if inter-day differences in performance at Pre may have influenced PAPE, we correlated the Pre-Post changes in impulse with performance at Pre relative to the four day average performance at Pre (Figure 3.1D). This analysis revealed a significant (*P*<0.001) inverse relationship between the two variables such that a relatively strong performance at Pre would tend to decrease the likelihood of seeing PAPE on that particular day.

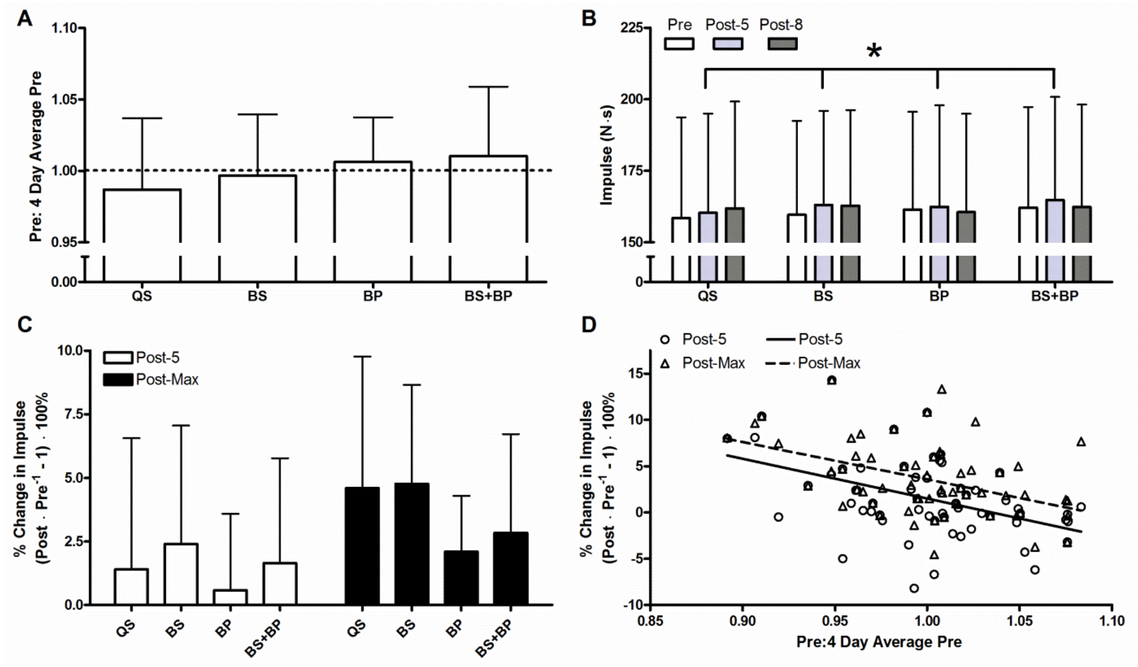

Figure 3.1. Squat jump performance during Pre and Post trials. A) Mean performance in Pre trials across the four test days (no significant differences). B) Jump impulse at each time point in the four test conditions. *- *P*<0.05 vs Pre C) PAPE at Post-5 and maximum PAPE in each test protocol (no significant differences between trials). D) Plot of PAPE at Post-5 and maximum PAPE versus the ratio of same-day Pre to the 4 day average of Pre values. Linear fits of the data have r^2 values of 0.20 for PAPE at Post-5 and 0.19 for maximum PAPE. Both slopes are significantly different from zero with *P*<0.001. In A-C, values are presented as means ± SEM; n=15. QS – Quiet Standing; BS – Back Squat; BP – Bench Press.

DISCUSSION

We aimed to determine if PAPE effects could be elicited when the CA and test activity activated different groups of muscles. We found PAPE effects during SJ in a group of trained swimmers at Post-5 in all CAs tested, including the QS condition. Since the appearance of PAPE is highly dependent on the individual being tested we also examined Post-Max, and again found jump impulse significantly improved relative to Pre but did not differ between CAs. The

PAPE we observed is consistent in timing and magnitude to that reported by other studies [7, 11, 20]. Interestingly, the higher demands of the BS+BP condition did not detract from SJ performance. The PAPE found following the QS CA was a surprising result which suggests that the modest performance enhancements seen in this study were a warm-up effect, probably caused by the SJ and PPU test protocol itself. The combination of upper and lower body activity in our test activity and the PAPE effect in the QS condition prevents a conclusion favoring either the presence or absence of a non-localized PAPE effect. This remains an important question in PAPE research which could be addressed using a modification of the current study design, focusing on the performance of a single test activity before and after a similar series of CAs. We also recommend a long delay between the pre-test and the CA to avoid potential warm-up effects from the pre-test. Given the uncertainty regarding the cause of PAPE, examination of electrically evoked twitch characteristics and electromyography also seem warranted in future work to differentiate between enhanced contractility and enhanced activation.

Although there were no systematic differences in performance during Pre trials, there was a significant negative correlation between how well our participants performance at Pre relative to the other test days and PAPE effects in SJ. This finding has implications for the testing of individual athletes, where an exemplar Pre performance would decrease the likelihood of seeing PAPE, and *vice versa*. This variability should be accounted for when assessing the effectiveness of a particular warm-up procedure. Future studies could benefit from the use of a large number of Pre tests to differentiate normal variability in performance from true PAPE effects.

An alternative interpretation of the data is that BP could be detrimental to SJ performance. Though not significant, Post-Max impulse was lower in BP and BS+BP than in QS and BS, and there were performance reductions at some Post time points relative to Pre seen in BP and BS+BP, but not in QS or BS. By extension it seems possible that high-level activation of non-specific muscle groups may impair performance. The implications of this interpretation further highlight the need to revisit the possible existence of non-localized PAPE effects using more sensitive and sport-specific tests.

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CHAPTER IV

- SQUAT JUMP AND JUMPING PUSH UP PERFORMANCE OF TRAINED SWIMMERS INMEDIATELY BEFORE AND AFTER RESISTANCE EXERCISE

Paper presented at the 11th World Congress of Performance Analysis of Sport,

Journal of Human Sport & Exercise (2017)

ABSTRACT

Introduction: When an action induces acute fatigue, it may be followed by a period of potentiated force production capability, termed as Postactivation Potentiation. The aim of the study was to measure the effect on performance of muscular contractions 5-20 minutes after a warm-up protocol and to determine the possible causes of performance changes. ***Methods:*** 15 Elite Canadian swimmers volunteered to participate in this study. A repeated measures counterbalanced design was used in which swimmers performed 4 different activation protocols in 4 different sessions. Muscle performance was evaluated in each participant performing 3 maximal effort squat jumps, alternated with 3 maximal jumping push-ups (denoted BME). Both assessed from one ground reaction force plate and EMG. Four repetitions of loaded back squat were applied when leg muscles were the target (CE-L). Four repetitions of loaded bench-press were applied when upper body muscles were the target group (CE-U). Loaded repetitions of back squat and bench press were combined applied when both limbs were the target (CE-L). After BME, muscle performance was assessed again at 5, 8, 12 and 20 minutes, regardless the CE applied. One test condition without any CE was also given and acted as a control. ***Results:*** Impulse in lower limbs was higher in the protocol CE-L (5min: 181.54 N·s; 8 min: 181.78 N·s), in comparison with pretest conditions (Pre: 175.18 N·s; P = 0.05). Impulse was also higher in CE-UL but it was achieved only after 8min of rest (181.16 N·s; p = 0.05) When comparisons with BME were made, the impulse in upper limbs was higher only in CE-U (50.58 N·s; p = 0.05), and this value was obtained at 8 minutes after load. ***Discussion & Conclusion:*** Improvements obtained in both limbs are in agreement with the physiological explanation of PAP. Changes happened in limbs after specific load application, but no influences were found when load applied in such limb was assessed in the other. Surprisingly, impulse was even higher at minute 8, and such effect achieved, could be related to a difference in involvement of motor units. Thus, although an improvement in performance is obtained after load application, PAP could not be considered only as an acute local effect generated by the myosin phosphorilation. This fact could suggest that some neural factors of the speedstrength behavior could be behind of the performance improvement of the system.

RESUMEN

Introducción: Cuando una acción induce fatiga aguda, puede estar seguida por un período de capacidad de producción de fuerza potenciada, denominada Potenciación post-activación. El objetivo del estudio fue medir el efecto en el rendimiento de las contracciones musculares realizadas de 5 a 20 minutos tras haber aplicado un protocolo de acondicimiento y determinar las posibles causas de los cambios en ese rendimiento. ***Método***: 15 nadadores canadienses de élite se ofrecieron como voluntarios para participar en este estudio. Se utilizó un diseño contrabalanceado de medidas repetidas en el que los nadadores realizaron 4 protocolos de activación diferentes en 4 sesiones diferentes. Se evaluó el rendimiento muscular en cada participante realizando 3 saltos desde media sentadilla, alternando con 3 flexiones con salto, ambos a máxima intensidad (Denominado BME). Los dos protocolos se evaluaron en una plataforma de fuerzas y mediante electromiografía de los músculos implicados (EMG). Se aplicaron cuatro repeticiones de media sentadilla cuando el objetivo era potenciar los músculos de la pierna (CE-L). Cuatro de press de banca cuando los músculos de la parte superior del cuerpo eran el objetivo (CE-U). Y también se aplicó un protocolo que combinó sentadillas y press de banca (CE-UL). Después de BME, el rendimiento muscular se evaluó nuevamente a los 5, 8, 12 y 20 minutos, independientemente del protocolo aplicado. Una condición de prueba sin ningún protocolo también se dio y actuó como control. ***Resultados:*** El impulso en extremidades inferiores fue mayor en el protocolo CE-L (5 min: 181,54 N • s; 8 min: 181,78 N • s), en comparación con condiciones de pretest (Pre: 175,18 N • s; P = 0,05). El impulso también fue mayor en CE-UL pero solo se logró después de 8min de descanso (181.16 N • s; p = 0.05) Cuando se hicieron comparaciones con CE, el impulso en extremidades superiores fue mayor solo en CE-U (50.58 N • s; p = 0.05), y este valor se obtuvo a los 8 minutos después de la carga. ***Conclusión***: Las mejoras obtenidas en ambas extremidades están de acuerdo con la explicación fisiológica del PAP. Los cambios ocurrieron en las extremidades después de la aplicación de carga específica, pero no se encontraron influencias cuando la carga aplicada en dicha extremidad se evaluó en la otra. Sorprendentemente, el impulso fue aún mayor en el minuto 8, y tal efecto logrado, podría estar relacionado con una diferencia en la participación de las unidades motoras. Por lo tanto, aunque se obtiene una mejora en el rendimiento después de la aplicación de la carga, la PAP no puede considerarse únicamente como un efecto local agudo generado por la fosforilación de la miosina. Este hecho podría sugerir que algunos factores neuronales del comportamiento de la fuerza de la velocidad podrían estar detrás de la mejora del rendimiento del sistema

INTRODUCTION

Nowadays, many authors show improvements in the execution of sporting gestures after warming up [1, 6, 7]. However, a method called Postactivation Potentiation (PAP) has recently been taken into consideration. A technique/procedure which produces an improvement in muscle contractility, both in strength and speed, by having previously applied maximal or submaximal loads on the muscle. The PAP effect is result of: A physiologic alteration which renders actin-myosin myofibril more sensitive to Ca^{2+} released from the sarcoplasmic reticulum, resulting in an increase on the cross-bridges attached inside the muscle fiber [24]; and a result of an increase of the muscle fiber recruitment as a consequence of an amplification of the motor-neuron's excitation [27, 28].

Nevertheless, one important fact is that myosin phosphorilation only occurs when fatigue, at low concentrations of Ca^{2+}, and its effects have been reported to dissipate after 5-8 minutes [5, 18, 35]. Considering cross bridges theory, if a sarcomere is phosphorilated, it is possible obtaining a gainance in the force exerted. But only when the fibers are stimulated become sensitive to be phosphorilated. Therefore, this is physiologically in conflict with some studies where a postexercise potentiation effect after 10-20 minutes is reported, and where the improvement has been justified though, by the augmented and maintained excitability of the neurosystem after such time [15, 20, 35], because if adaptations came at the level of the spinal cord, the application of an acute load in an specific muscle group could be questionable.

So, the question which remains unclear is whether, and to what extent, the short term potentiation of speed-strength by conditioning exercises can be considered as an acute local effect generated by the myosin phosphorilation, or as general effect, caused by neuronal factors of speed-strength behavior. Our hypothesis is that only the muscles who receive the load are able of being phosporilated and therefore, potentiated.

The use of swimmers allows us to assess muscle performance in 2 separate muscle groups, the initial push off phase from the block start requires the explosive power of the muscles of the legs [15], while the assessment of upper body muscles could give us information related with some particular swimming styles. Sprint swimmers are characterized for developing a high power in a short amount of time. High power and speed are only achieved for those athletes with a high percentage of fast fiber composition, where these methods have resulted to be valid. Results from the test could indicate us if swimmers could benefit for the use of this kind of techniques.

The purpose of this study was to test systematically if muscular performance can indeed be elevated by brief, high-force contractions 5-20 minutes prior to competition and to determine the possible causes for the reputed performance enhancement.

METHODS:

Experimental approach to the problem

A repeated measures counterbalanced design was used in which swimmers performed 4 different activation protocols in 4 different sessions. Muscle performance was evaluated in each participant performing 3 maximal effort vertical jumps (squat jumps) alternated with 3 maximal effort push-ups (flying style). Squat jumps performance was assessed from the ground reaction force exerted on the force plates, with subsequent landing on the same plate. EMG acquisition was registered for two muscles in lower and upper limbs in all tests. The 3 maximal effort push-ups were performed on the same way than the legs, with both hands on the plate. This sequence was noted as the basic muscle evaluation protocol (BME) (Figure 4.1).

Figure 4.1. Basic muscle evaluation protocol (BME).

One bout of loaded conditioning exercise (CE) on the target muscles was randomly applied on the subjects after the BME. Four repetitions of loaded back squat were applied when the leg muscles were the target (CE-L). Four repetitions of loaded bench-press were applied when the upper body muscles were the target group (CE-U). Loaded repetitions of back squat and bench press were combined applied in lower and upper limbs when both limbs were the target (CE-UL). After CE, muscle performance was assessed again in back squats and Push Ups at 5, 8, 12 and 20 minutes later, regardless the CE applied. One test condition without any CE was also given and acted as a control.

Subjects

Fifteen varsity level swimmers (8 males and 7 females) volunteered to participate in this study (mean ± SD, Age: 19.4 ± 1.4 years, Weight: 78.6 ± 9.0 kg [males], 65.4 ± 8.5 kg [females], Height: 1.83 ± 0.02 m [males], 1.64 ± 0.06 m [females]). Swimmers were in their competition period and had participated in national and international competitions for at least 1 year prior to the start of the study. The swimmers habitually trained 6 days per week using a complex training protocol which allowed the development of power and speed while decreasing the volume of aerobic training [22]. None of the swimmers were taking drugs, medication, or dietary supplements known to influence physical performance. Tests were scheduled to take place prior to their daily training regimen, and subjects were instructed to avoid any physical exertion prior to testing. Test familiarization was performed during their dry practices held three times per week. During the familiarization period, the load required to perform a 1 repetition maximum (1RM) lift was determined for back squat and bench press according American College of Sports Medicine guidelines (Armstrong *et al.* 2006). The 1RM for back squat was 90.7 ± 17.0 kg for males and 53.1 ± 14.1 kg for females. The 1RM (mean ± SD) for bench press was 71.3 ± 12.2 kg for males and 34.1 ± 10.3 kg for females. All experiments were performed in the Olympic Oval at the University of Calgary. Subjects signed an informed consent form which was reviewed and approved by the Conjoint Health Research Ethics Board at the University of Calgary (REB 15-1135).

Impulse analysis

Muscle force was inferred from the vertical impulse obtained by the ground reaction force plate (PASCO®, PS-2141. Roseville, CA 95747 USA). The data acquisition software (DataStudio, version 1.9.8r10) collected values at a sampling rate of 1000 Hz. Impulse was determined by using the formula of the impulse theorem subtracting body weight from the force time curve and integrating with respect to time (Figure 4.2).

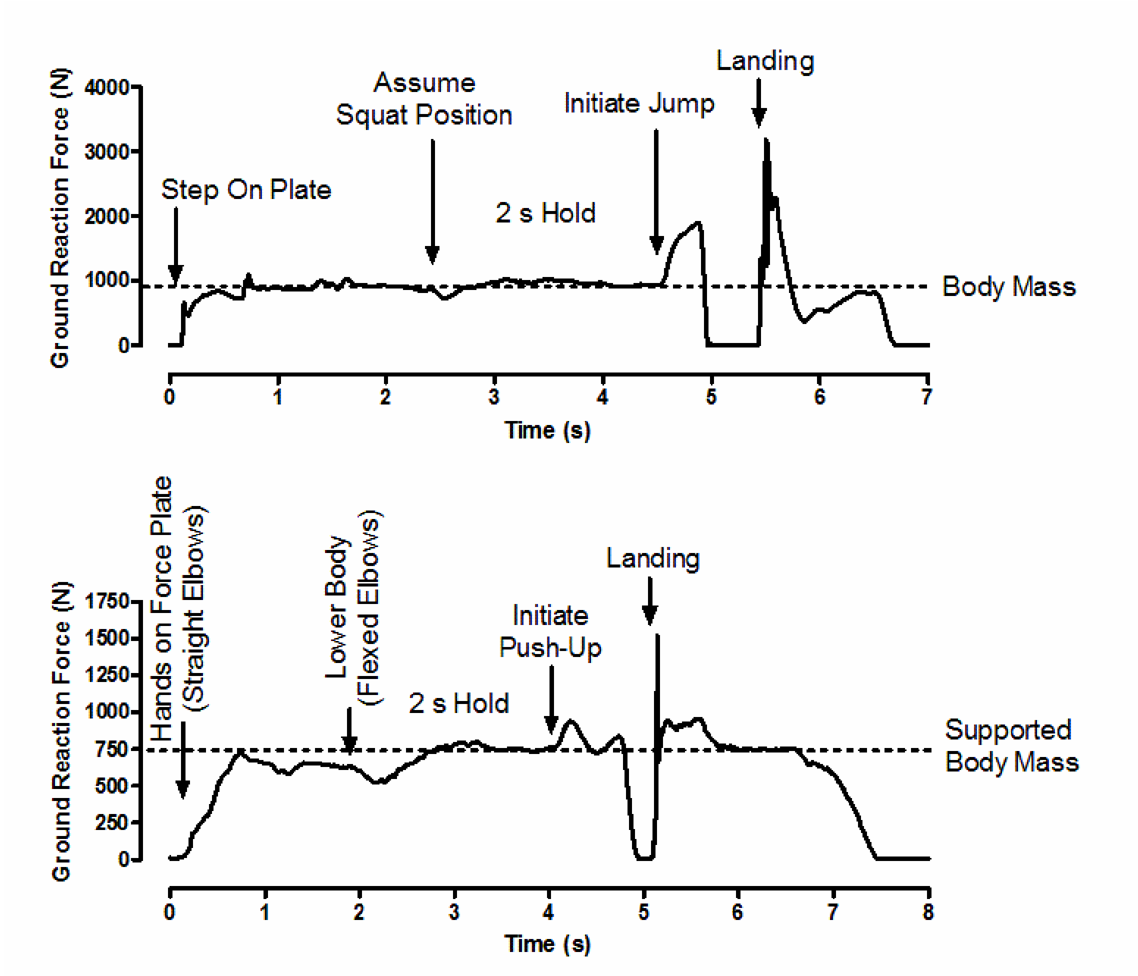


Figure 4.2: Sample ground reaction forces during a squat jump (top) and maximal effort push-up (bottom).

EMG Activity

Bilateral surface electromyography (EMG) from the muscles of each participant was recorded for assessing muscle activation. Pairs of self-adhesive electrodes (Norotrode 20^{TM}. Myotronics Inc. Kent, USA) were placed according to Kasman, (2002)[23], in Rectus Femoris, Vastus Lateralis, Pectoralis Major, and Triceps Brachii with an interelectrode distance of 20mm (Figure 4.3). Electrodes were placed in the presumed underlying direction of the muscle fibres.

EMG was sampled at a 2k Hz for upper limbs and at a 1k Hz for lower limbs, common mode rejection ratio: 110 dB, amplified and band-pass filtered (8-500Hz). The myoelectric signals were acquired and filtered using the analysis software Windaq (DATAQ Instruments®, Inc. Akron, OH 44333, USA), and the EMG signals were then processed using the root mean square algorithm (RMS).

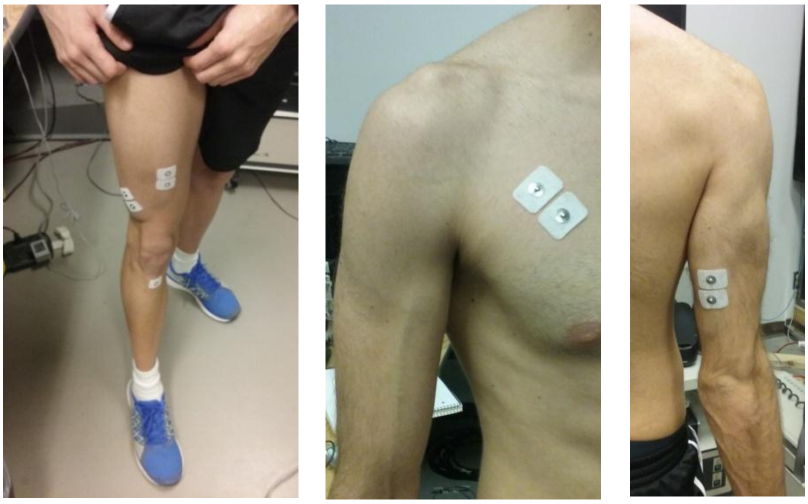


Figure 4.3. Pairs of self-adhesive electrodes (Norotrode 20™. Myotronics Inc. Kent, USA) placed according to Kasman (2002)[23], in Rectus Femoris, Vastus Lateralis, Pectoralis Major, and Triceps Brachii.

PROCEDURES:

Subjects came to the laboratory on 4 separate occasions for being tested in the different experimental situations. In none of those times they took drugs, medication, or dietary supplements known to influence physical performance. Previously the intervention was done, they were exposed to the testing methods several times before, with the purpose of determining the normal biological variation in response to the traditional warm ups and in order of avoiding the fatigue/ learning effects during testing. Throughout this period, RM values were also obtained. The experimental setting was the Human Performance Laboratory from the Faculty of Kinesiology at the University of Calgary (Canadá), which is equipped with force plates, EMG devices and strength training equipment. Since arrival, the skin was prepared, EMG electrodes were positioned on the muscles and interelectrode resistance was checked (<5k Ω).

Three Squat Jumps and Explosive Push Ups were performed alternatively with 5 seconds of rest between each repetition for avoiding the carryover effect from one movement to the other. After adopting the initial position on the force platform, subjects were requested of maintaining it during three seconds for reducing the elastic elements of force development in muscles. Encouraged verbal signal was given as a start command. This was considered the basic muscle evaluation protocol (BME) or pre test, and identical conditions were repeated as post test at 5, 8, 12 and 20 minutes after the conditioning exercise.

The conditioning exercises were randomly applied just 30-60 seconds after the last explosive push up of the pre test. Loaded back squat and loaded bench press were chosen as conditioning exercises for lower and upper limbs respectively. Four repetitions were executed in each conditioning exercise case at a percentage relative to 90% of 1RM. Both exercises were done in a Power Rack and two spotters assisted and controlled movement and specific loads of subjects. Squat Jumps and Flying Push Ups were evaluated in all cases, regardless the conditioning exercise applied. These conformed four different conditions: The first one consisted in doing nothing between pre and post test and acting as controls. The second one consisted in the application of loaded back squats only (CE-L) as an extra load for the lower limbs. The third consisted in the application of loaded bench press only (CE-U) as an extra load for the upper limbs. And the fourth one consisted in applied both loaded back squat and bench press (CE-UL).

Statistical analysis

Statistical analysis was performed using SPSS Version 21.0 (IBM, Chicago, IL, USA). Descriptive statistics were obtained and data were expressed as the mean ± SD and the confidence interval. The test-retest reliability (intraclass correlation [ICC]) within and between observers was analyzed for the all variables. After testing for the normality distribution, a separate 2-way (time x condition) repeated measures ANOVAs were applied to compare changes in Impulse and EMG before and 5, 8, 12 and 20 minutes after each conditioning exercise. To detect difference within protocols, significance was accepted at the *alpha* < 0.05 level and paired comparisons were used in conjunction with Holm’s Bonferroni method for a control of the type 1 error.

Pearson's correlation analyses were used to assess the relationship between Impulse and EMG values. For all statistical analyses, the level of significance was set at level 0.05. When relations were not significant, data were split into gender and analyzed by Spearman's correlation coefficient.

RESULTS

Differences in IMPULSE were found in LL in CE-L ($F_{4,11} = 5.714$, $p = 0.01$). Comparing with values achieved in Pretest (175.18 ± 8.70 N·s), values of impulse were higher at 5 minutes after the load application (181.54 ± 8.76, N·s; $p = 0.05$), and at 8 minutes (181.78 ± 9.01 N·s; $p = 0.035$), representing an improvement in jump impulse near to 5% (Table 4.1; Figure 4.4). No influence of the treatment applied was registered at 12 or 20 minutes after. No statistically significant differences were found in UL performance in CE-L (Table 4.2; Figure 4.5). When data were split into gender, analysis revealed slight improvements in males, meanwhile a no variation in females performance with a deep decreasing at minute 20 ($F_{4,3} = 13.887$, $p = 0.02$).

No differences in LL performance were reached in CE-U after load application (Table 4.1, Figure 4.4). Values obtained in CE-U for UL showed differences after load application ($F_{4,11} = 3.681$, $p < 0.05$). Post hoc test, showed a higher impulse registered at minute 8 in comparison with the values obtained in the other intervals of time (Imp: 50.18 ± 3.83 N·s; $p = 0.02$) (Table 4.2, Figure 4.5). Such improvement meant almost a 10% of improvement respect to pretest conditions.

Analysis carried out in CE-UL revealed differences in impulse values performed with LL ($F_{4,11} = 4.214$, $p = 0.026$). Post hoc analysis only remarked results obtained at minute 8 after the load application**,** (Imp: 181.16 N·s; $p = 0.05$) (Table 4.1, Figure 4.4). When the same analysis was applied for UL, statistical differences were shown ($F_{4,11} = 3.665$, $p = 0.039$). Performance was a 5% better at minute 8 (50.01 ± 4.286 N·s), than achieved at 5 minutes (48.33 ± 4.182 N·s). However, such differences were not statistically revealed by Bonferroni test and them only indicated a decreasing trend in performance after minute 12 (Table 4.2, Figure 4.5).

Values of EMG obtained in RF in CE-L maintained unvaried on the first stages of the test and did not reveal significant differences. Such a trend was similar in the results obtained in VL, although it was found a decreasing trend supported by statistical significance ($F_{4,11}$ = 3.308, p = 0.05). EMG maintained high until minute 8, and a loss of it was registered since minute 12 (p = 0.038), (Table 4.3; Figure 4.4). EMG data registered in TB and PM not reached differences statistically significant, but a progressive decreasing is observed in those values along the test, especially on the last stages (Figure 4.5).

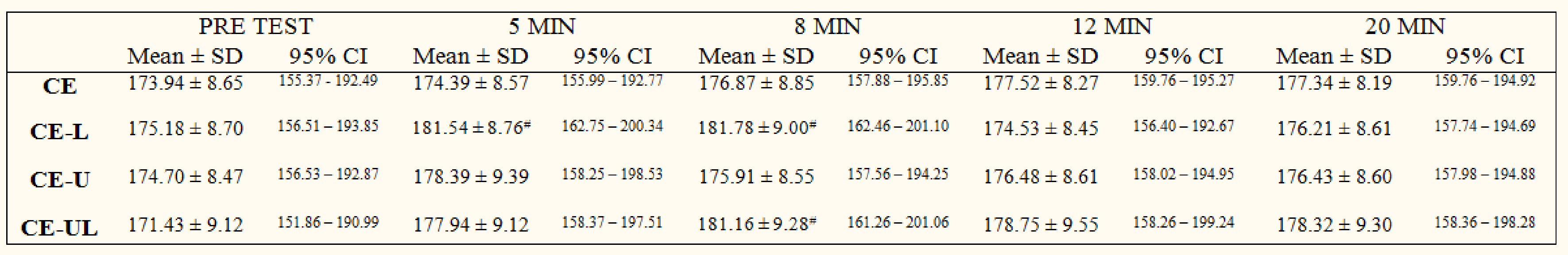
No statistical differences in EMG were found in the muscles of the LL in CE-U, neither in RF nor VL (Table 4.3, Figure 4.4**.** Considering upper limbs muscles, the effect of the load was close to be significant due to the increasing in EMG measurements at 5 minutes after the load application, both in TB (EMG = 1.161 ± 0.085 mV, p = 0.06), and in PM (EMG = 0.646 ± 0.062 mV , p = 0.1) (Table 4.4, Figure 4.5). After that, EMG decreased along the test.

No significant changes were registered in CE-UL for EMG measurements in RF and VL (Table 4.3). Differences in TB values were detected ($F_{4,11}$ = 3.461, p = 0.046) and Bonferroni test revealed significance on performance at 5 minutes after the load application (EMG: 1.13 ± 0.084mV, p = 0.046). Alternatively, statistical analysis carried out with EMG values obtained from PM revealed high differences ($F_{4,11}$ = 4.327, p = 0.024), and came from a decreasing trend along the test. Bonferroni post hoc analysis could not reveal more details, though. (Table 4.4, Figure 4.5).

In CE-L**,** Pearson's correlation coefficient did not show associations between impulse and EMG values neither LL nor UL (Tables 4.5 & 4.6). Nevertheless, Spearman's analysis showed in females a negative association between RF and impulse of LL, corresponding to low values in impulse related with high values in EMG. Those correlations were found in pretest (r= -0.821, p = 0.023), at minute 8 (-0.786, p = 0.036) and at minute 12 (-0.821, p = 0.023).

Pearson's correlation analysis did not reveal in CE-U associations between EMG in LL and UL muscles and Impulse (Tables 4.5 & 4.6). Spearman's analysis just showed isolated associations; in males at minute 20, where high values of EMG in RF were related with low values of impulse (r = -0.786, p = 0.021) (Table 4.5); and in females, with an inverse correlation in TB at minute 20 (r = -0.775, p = 0.041), where a recovery of the EMG values caused a drop of the values of Impulse exerted (Table 4.6).

In CE-UL, males who expressed high values of EMG for RF in pretest, were those who produced less impulse with the lower limbs in the force plate, as was expressed by the Spearman's correlation coefficient (r = -0.857, p = 0.007), this fact was repeated at 5 and 12 minutes (Table 4.5). In TB, values obtained at minute 5 in males were close to be significant by Spearman's coefficient, expressing that high EMG values were related with high values of impulse (r = 0.762, p = 0.058), but it was only a trend (Table 4.6).



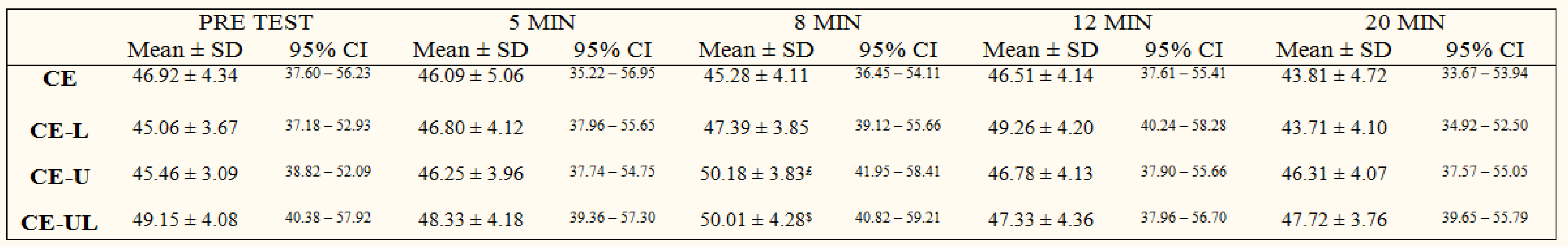
	PRE TEST		5 MIN		8 MIN		12 MIN		20 MIN	
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI
CE	173.94 ± 8.65	155.37 - 192.49	174.39 ± 8.57	155.99 – 192.77	176.87 ± 8.85	157.88 – 195.85	177.52 ± 8.27	159.76 – 195.27	177.34 ± 8.19	159.76 – 194.92
CE-L	175.18 ± 8.70	156.51 – 193.85	181.54 ± 8.76$^{\#}$	162.75 – 200.34	181.78 ± 9.00$^{\#}$	162.46 – 201.10	174.53 ± 8.45	156.40 – 192.67	176.21 ± 8.61	157.74 – 194.69
CE-U	174.70 ± 8.47	156.53 – 192.87	178.39 ± 9.39	158.25 – 198.53	175.91 ± 8.55	157.56 – 194.25	176.48 ± 8.61	158.02 – 194.95	176.43 ± 8.60	157.98 – 194.88
CE-UL	171.43 ± 9.12	151.86 – 190.99	177.94 ± 9.12	158.37 – 197.51	181.16 ± 9.28$^{\#}$	161.26 – 201.06	178.75 ± 9.55	158.26 – 199.24	178.32 ± 9.30	158.36 – 198.28

Table 4.1, Mean, SD and Confidence Interval of Impulse in Lower Limbs in the four different protocols in five periods of time (n=15).

Significant difference in Impulse (p<0.05) between pretest and such a time

$ Significant difference in Impulse (p<0.05) between 5min and such a time

£ Significant difference in Impulse (p<0.05) between such a time and the rest of periods



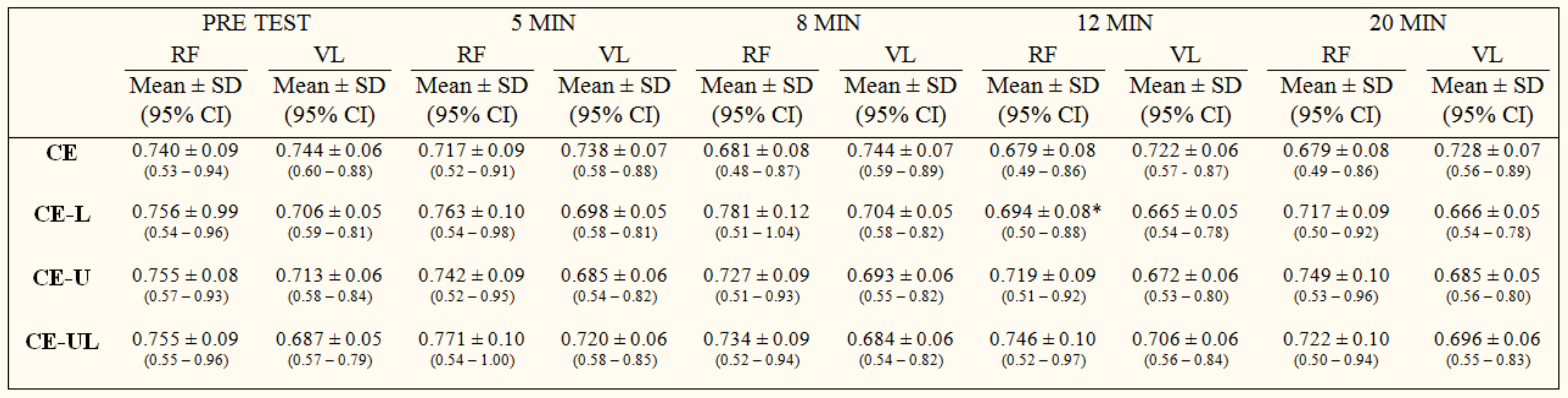
	PRE TEST		5 MIN		8 MIN		12 MIN		20 MIN	
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI
CE	46.92 ± 4.34	37.60 – 56.23	46.09 ± 5.06	35.22 – 56.95	45.28 ± 4.11	36.45 – 54.11	46.51 ± 4.14	37.61 – 55.41	43.81 ± 4.72	33.67 – 53.94
CE-L	45.06 ± 3.67	37.18 – 52.93	46.80 ± 4.12	37.96 – 55.65	47.39 ± 3.85	39.12 – 55.66	49.26 ± 4.20	40.24 – 58.28	43.71 ± 4.10	34.92 – 52.50
CE-U	45.46 ± 3.09	38.82 – 52.09	46.25 ± 3.96	37.74 – 54.75	50.18 ± 3.83$^{\pounds}$	41.95 – 58.41	46.78 ± 4.13	37.90 – 55.66	46.31 ± 4.07	37.57 – 55.05
CE-UL	49.15 ± 4.08	40.38 – 57.92	48.33 ± 4.18	39.36 – 57.30	50.01 ± 4.28$^{\$}$	40.82 – 59.21	47.33 ± 4.36	37.96 – 56.70	47.72 ± 3.76	39.65 – 55.79

Table 4.2, Mean, SD and Confidence Interval of impulse in Upper Limbs in the four different protocols in five periods of time (n=15).

Significant difference in Impulse (p<0.05) between pretest and such a time

$ Significant difference in Impulse (p<0.05) between 5min and such a time

£ Significant difference in Impulse (p<0.05) between such a time and the rest of periods



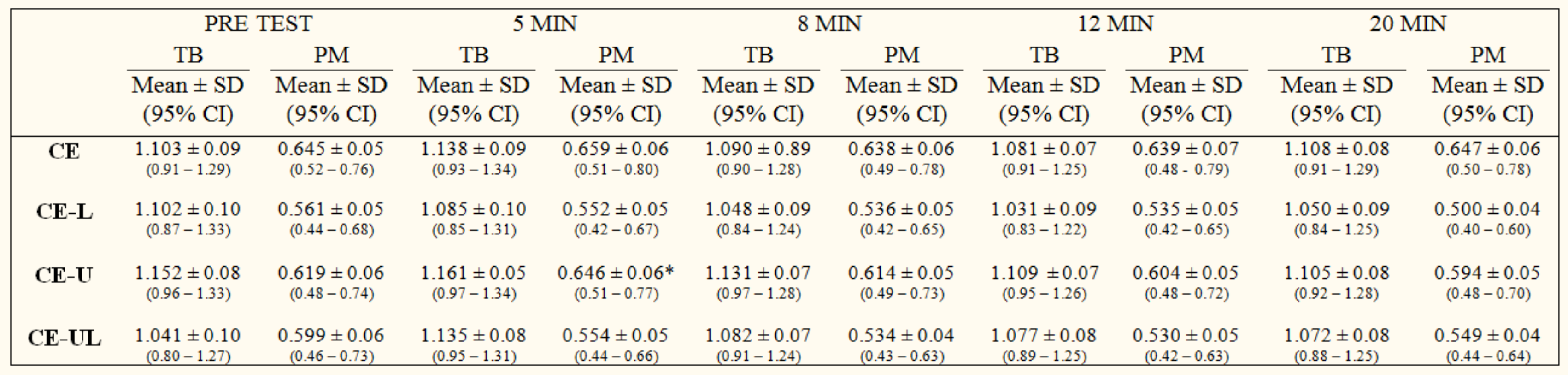
	PRE TEST		5 MIN		8 MIN		12 MIN		20 MIN	
	RF	VL	RF	VL	RF	VL	RF	VL	RF	VL
	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)
CE	0.740 ± 0.09 (0.53 – 0.94)	0.744 ± 0.06 (0.60 – 0.88)	0.717 ± 0.09 (0.52 – 0.91)	0.738 ± 0.07 (0.58 – 0.88)	0.681 ± 0.08 (0.48 – 0.87)	0.744 ± 0.07 (0.59 – 0.89)	0.679 ± 0.08 (0.49 – 0.86)	0.722 ± 0.06 (0.57 - 0.87)	0.679 ± 0.08 (0.49 – 0.86)	0.728 ± 0.07 (0.56 – 0.89)
CE-L	0.756 ± 0.99 (0.54 – 0.96)	0.706 ± 0.05 (0.59 – 0.81)	0.763 ± 0.10 (0.54 – 0.98)	0.698 ± 0.05 (0.58 – 0.81)	0.781 ± 0.12 (0.51 – 1.04)	0.704 ± 0.05 (0.58 – 0.82)	0.694 ± 0.08* (0.50 – 0.88)	0.665 ± 0.05 (0.54 – 0.78)	0.717 ± 0.09 (0.50 – 0.92)	0.666 ± 0.05 (0.54 – 0.78)
CE-U	0.755 ± 0.08 (0.57 – 0.93)	0.713 ± 0.06 (0.58 – 0.84)	0.742 ± 0.09 (0.52 – 0.95)	0.685 ± 0.06 (0.54 – 0.82)	0.727 ± 0.09 (0.51 – 0.93)	0.693 ± 0.06 (0.55 – 0.82)	0.719 ± 0.09 (0.51 – 0.92)	0.672 ± 0.06 (0.53 – 0.80)	0.749 ± 0.10 (0.53 – 0.96)	0.685 ± 0.05 (0.56 – 0.80)
CE-UL	0.755 ± 0.09 (0.55 – 0.96)	0.687 ± 0.05 (0.57 – 0.79)	0.771 ± 0.10 (0.54 – 1.00)	0.720 ± 0.06 (0.58 – 0.85)	0.734 ± 0.09 (0.52 – 0.94)	0.684 ± 0.06 (0.54 – 0.82)	0.746 ± 0.10 (0.52 – 0.97)	0.706 ± 0.06 (0.56 – 0.84)	0.722 ± 0.10 (0.50 – 0.94)	0.696 ± 0.06 (0.55 – 0.83)

Table 4.3, Mean, SD and Confidence Interval of EMG in Lower Limbs in the four different protocols in five periods of time (n=15).

Significant difference in EMG (p<0.05) between pretest and such a time

$ Significant difference in EMG (p<0.05) between 5min and such a time

£ Significant difference in EMG (p<0.05) between such a time and the rest of periods



	PRE TEST		5 MIN		8 MIN		12 MIN		20 MIN	
	TB	PM	TB	PM	TB	PM	TB	PM	TB	PM
	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)
CE	1.103 ± 0.09 (0.91 – 1.29)	0.645 ± 0.05 (0.52 – 0.76)	1.138 ± 0.09 (0.93 – 1.34)	0.659 ± 0.06 (0.51 – 0.80)	1.090 ± 0.89 (0.90 – 1.28)	0.638 ± 0.06 (0.49 – 0.78)	1.081 ± 0.07 (0.91 – 1.25)	0.639 ± 0.07 (0.48 - 0.79)	1.108 ± 0.08 (0.91 – 1.29)	0.647 ± 0.06 (0.50 – 0.78)
CE-L	1.102 ± 0.10 (0.87 – 1.33)	0.561 ± 0.05 (0.44 – 0.68)	1.085 ± 0.10 (0.85 – 1.31)	0.552 ± 0.05 (0.42 – 0.67)	1.048 ± 0.09 (0.84 – 1.24)	0.536 ± 0.05 (0.42 – 0.65)	1.031 ± 0.09 (0.83 – 1.22)	0.535 ± 0.05 (0.42 – 0.65)	1.050 ± 0.09 (0.84 – 1.25)	0.500 ± 0.04 (0.40 – 0.60)
CE-U	1.152 ± 0.08 (0.96 – 1.33)	0.619 ± 0.06 (0.48 – 0.74)	1.161 ± 0.05 (0.97 – 1.34)	0.646 ± 0.06* (0.51 – 0.77)	1.131 ± 0.07 (0.97 – 1.28)	0.614 ± 0.05 (0.49 – 0.73)	1.109 ± 0.07 (0.95 – 1.26)	0.604 ± 0.05 (0.48 – 0.72)	1.105 ± 0.08 (0.92 – 1.28)	0.594 ± 0.05 (0.48 – 0.70)
CE-UL	1.041 ± 0.10 (0.80 – 1.27)	0.599 ± 0.06 (0.46 – 0.73)	1.135 ± 0.08 (0.95 – 1.31)	0.554 ± 0.05 (0.44 – 0.66)	1.082 ± 0.07 (0.91 – 1.24)	0.534 ± 0.04 (0.43 – 0.63)	1.077 ± 0.08 (0.89 – 1.25)	0.530 ± 0.05 (0.42 – 0.63)	1.072 ± 0.08 (0.88 – 1.25)	0.549 ± 0.04 (0.44 – 0.64)

Table 4.4, Mean, SD and Confidence Interval of EMG in Lower Limbs in the four different protocols in five periods of time (n=15).

Significant difference in EMG (p<0.05) between pretest and such a time

$ Significant difference in EMG (p<0.05) between 5min and such a time

£ Significant difference in EMG (p<0.05) between such a time and the rest of periods

		PRE TEST				5 MIN				8 MIN				12 MIN				20 MIN			
		RF		VL		RF		VL		RF		VL		RF		VL		RF		VL	
		r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P
CE	**a**	-.148	.592	-.283	.301	-.048	.868	-.267	.336	-.052	.853	-.291	.290	-.017	.957	-.323	.246	-.119	.672	-.331	.220
	b	-.667	.071	.024	.955	-.667	.071	-.024	.955	-.500	.207	-.167	.693	-.286	.493	-.071	.867	-.381	.352	-.143	.736
	c	.036	.939	.429	.337	-.357	.432	-.071	.879	-.321	.482	.036	.939	-.321	.482	-.107	.819	-.393	.383	-.107	.819
CE-L	**a**	-.106	.702	.048	.866	-.051	.857	.229	.413	.010	.973	.186	.506	-.123	.663	.187	.504	-.045	.873	.174	.536
	b	-.571	.139	-.571	.139	-.476	.233	-.357	.385	-.500	.207	-.476	.233	-.476	.233	-.143	.736	-.429	.289	-.407	.317
	c	-.893*	.007	.250	.589	-.679	.094	.179	.702	-.786*	.036	-.071	.879	-.821*	.023	.143	.760	-.571	.180	.429	.337
CE-U	**a**	-.082	.772	.149	.595	-.049	.862	.337	.219	-.032	.909	.322	.226	.073	.797	.327	.233	-.059	.836	.336	.221
	b	-.548	.160	-.357	.385	-.714*	.047	-.381	.352	-.571	.139	-.190	.651	-.643	.086	-.119	.779	-.786*	.021	-.381	.352
	c	-.643	.119	.679	.094	-.643	.119	.679	.094	-.607	.148	.429	.337	-.750	.052	.607	.148	-.321	.482	.643	.119
CE-UL	**a**	-.123	.663	.059	.835	-.135	.631	.031	.912	-.068	.810	.128	.649	-.040	.887	.069	.808	.011	.968	.153	.585
	b	-.857*	.007	-.524	.183	-.714*	.047	-.500	.207	-.619	.102	-.476	.233	-.714*	.047	-.738*	.037	-.690	.058	-.476	.233
	c	.429	.337	.143	.760	-.429	.337	.000	1.0	-.429	.337	.107	.819	-.071	.879	.143	.760	.378	.403	.036	.939

Table 4.5. Correlation coefficients between Impulse in Lower Limbs and EMG in Rectus Femoris (RF) and Vastus Laterallis (VL). Coefficients showed for each Protocol as: (a) Pearson's Correlation Coefficient analyzed in Both Genders; (b) Spearman's Correlation Coefficient analyzed in Males; (c) Spearman's Correlation Coefficient, analyzed in Females.

*Significance <0.05

		PRE TEST				5 MIN				8 MIN				12 MIN				20 MIN			
		TB		PM		TB		PM		TB		PM		TB		PM		TB		PM	
		r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P	r	P
CE	**a**	.444	.097	.532*	.041	.565	.028	.403	.136	.499	.058	.366	.179	.509	.053	.388	.152	.530*	.042	.455	.088
	b	.524	.183	.167	.693	.595	.120	.143	.736	.762*	.028	.000	1.0	.690	.058	.024	.955	.619	.102	.190	.651
	c	.071	.879	.357	.432	.179	.702	.500	.253	-.036	.939	.500	.253	.143	.760	.464	.294	-.045	.873	.174	.536
CE-L	**a**	.201	.472	.217	.436	.311	.260	.161	.568	.258	.354	.270	.330	.159	.571	.172	.540	.319	.247	.275	.321
	b	.096	.821	.476	.233	.095	.823	.143	.736	.095	.823	.095	.823	-.190	.651	.024	.955	.190	.655	.286	.493
	c	-.429	.337	-.179	.702	-.500	.253	-.179	.702	-.357	.432	.107	.819	-.179	.702	.036	.939	.321	.482	.214	.645
CE-U	**a**	.110	.696	.213	.445	.246	.377	-.001	.997	.122	.665	.014	.961	.243	.383	.039	.891	.340	.215	.237	.395
	b	.024	.955	.286	.493	.143	.736	.214	.610	.286	.493	.262	.531	-.119	.779	-.024	.955	.262	.531	.190	.651
	c	-.500	.253	.288	.531	-.396	.379	-.252	.585	-.714	.071	-.179	.702	-.679	.094	-.214	.645	-.775*	.041	.071	.879
CE-UL	**a**	.425	.114	.346	.206	.486	.066	.179	.523	.472	.076	.253	.363	.393	.148	.366	.179	.426	.114	.307	.266
	b	.500	.207	.048	.911	.762*	.028	.048	.911	.429	.289	-.119	.779	.060	.888	.167	.693	.500	.207	.286	.493
	c	.250	.589	.000	1.0	-.071	.879	.000	1.0	-.357	.432	.000	1.0	-.179	.702	.286	.535	-.536	.215	.107	.819

Table 4.6. Correlation coefficients between Impulse in Upper Limbs and EMG in Triceps Brachii (TB) and Pectoralis Major (PM). Coefficients showed for each Protocol as: (a) Pearson's Correlation Coefficient analyzed in Both Genders; (b) Spearman's Correlation Coefficient analyzed in Males; (c) Spearman's Correlation Coefficient, analyzed in Females.

*Significance <0.05

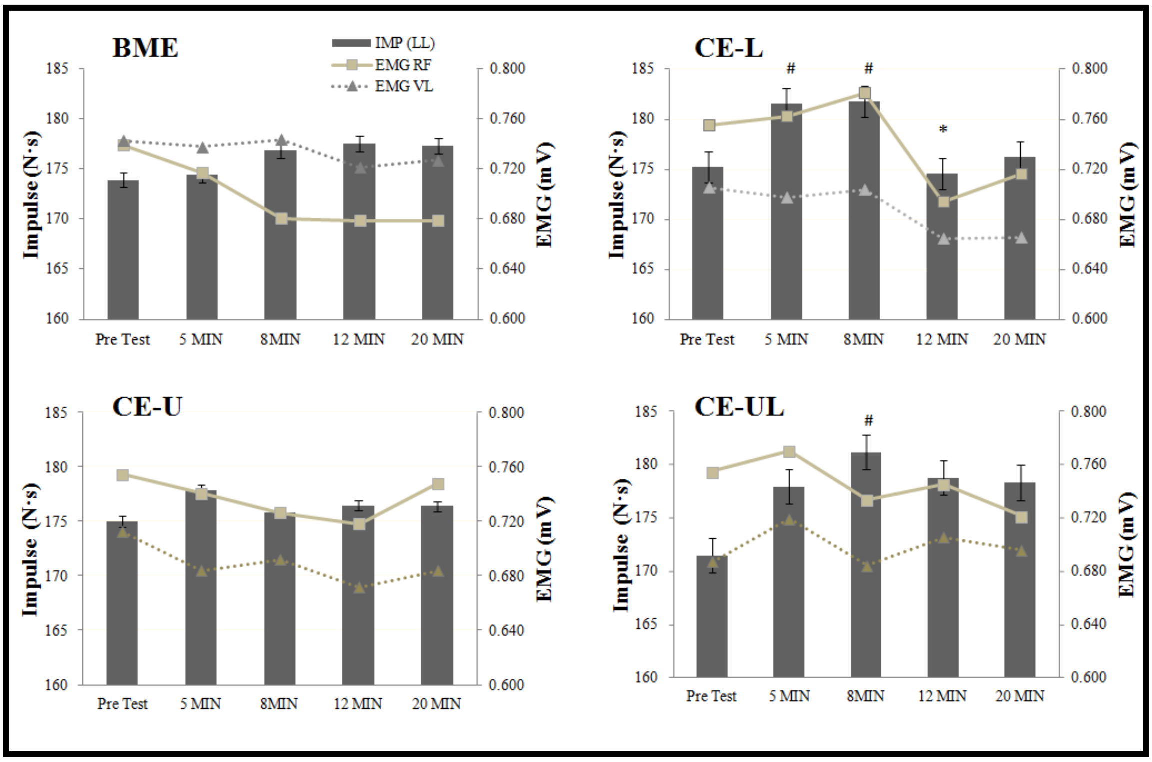


Figure 4.4. Lower Limbs Impulse and EMG (Rectus Femoris and Vastus Laterallis) (N=15).

Significant difference in Impulse ($p<0.05$) between pretest and such a time

$ Significant difference in Impulse ($p<0.05$) between 5min and such a time

£ Significant difference in Impulse ($p<0.05$) between such a time and the rest of periods

* Significant differences in EMG ($p<0.05$) between pretest and such a time

€ Significant differences in EMG ($p<0.05$) between 5min and such a time

& Significant differences in EMG ($p<0.05$) between such a time and the rest of periods

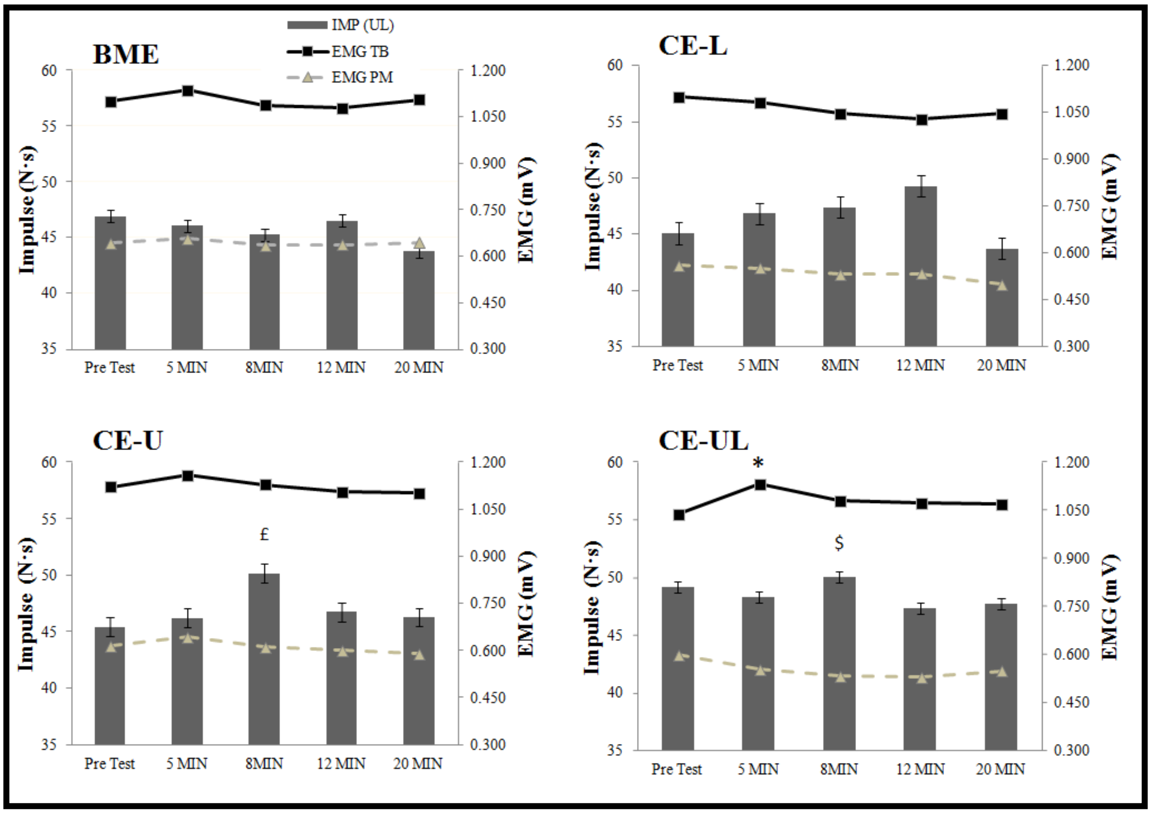


Figure 4.5. Upper Limbs Impulse and EMG (Triceps Brachii and Pectorailis Major) (N=15).

Significant difference in Impulse ($p<0.05$) between pretest and such a time

$ Significant difference in Impulse ($p<0.05$) between 5min and such a time

£ Significant difference in Impulse ($p<0.05$) between such a time and the rest of periods

* Significant differences in EMG ($p<0.05$) between pretest and such a time

€ Significant differences in EMG ($p<0.05$) between 5min and such a time

& Significant differences in EMG ($p<0.05$) between such a time and the rest of periods

DISCUSSION

The purpose of this study was to test systematically if muscular performance could be elevated by brief, high-force contractions 5-20 minutes prior to competition and to determine the possible causes for the reputed performance enhancement. Results obtained showed that muscle performance could be improved for a period no longer than 5-8 minutes after having previously applied heavy loads on it. Nevertheless, in spite of results would be related with the physiological theory of Postactivation Potentiation, evoked by myosin phosphorilation, neuromuscular factors could contain the effectiveness key of such effect.

An optimal preparation (warm up) is necessary to achieve the highest possible realization of speed-strength in training and competition [19]. The use of swimmers allowed us to assess muscle performance in 2 separate muscle groups, legs (quadriceps group of muscles) and upper body (triceps and pectoralis). The initial push off phase from the block start requires a high impulse achieved with legs [9, 16], especially in breaststrokers, in which movements performed under the water are limited. On the other hand, the strenuous use of the upper body could have given us some information about such swimming style, in which a constant loss of streamline position is solved with explosive movements executed by arms and legs [29, 32]. However, no relations were found between upper limbs performance and swimmers preferred style.

Analyses by gender were also observed on this study because literature has shown variances on the results [35]. Usually males show better results after applying PAP protocols because fast fibers are more frequent on them. But it seems important to note that the level or status of training is as much important factor as gender [9, 11].

No significant differences in performance were found in CE, neither LL, nor UL. Our protocol did not revealed a negative influence of fatigue in performance variation along the test, being less than 2% between the highest and lowest value achieved in LL, and less than 5% between the highest and the lowest value registered in UL. Considering the difficulty of the jumping push-ups and the longer recovery time due to the glycolitic characteristics of the fast twitch fibers, a deterioration of the values obtained on the impulse along the test would be expected, but it did not occur. Neither in lower limbs [39].

LL impulse performance improved in CE-L, and UL impulse improved in CE-U, both at 5 minutes after load application. Lower Limbs also showed better results in CE-UL protocol at minute 5 as is observed in Figure 3.4. These results are in agreement with numerous studies testing PAP effects in performance [2, 25, 38]. Surprisingly, impulse was even higher for LL and UL at minute 8, in CE-L, CE-U and CE-UL (Impulse in CE-UL; LL: 6% higher than Pretest condition, UL: 5% higher than performance at minute 5) (Figures 4.4 & 4.5). Potentiation effect achieved in this study at minute 8 could be related to a difference in involvement of motor units. It is indeed well established that a greater number of motor units are recruited during fast voluntary contractions performed at similar intensities. Enhanced motor unit recruitment during fast contractions involves units with higher recruitment threshold (comprising fast-twitch muscle fibers) that display greater PAP capacity than motor units with lower recruitment threshold [3-5]. Therefore, PAP effects could be enlarged applying explosive movements after some time of rest. According to DeRenne (2010)[11], Brandenburg (2005)[8] and Baker (2003)[2], the speed of the movements could have an important role on the activation of the fast units, so high intensity stimulus (100%) performed at slower speed could have an attenuation effect of the neural output, reducing the possibility of favorable adaptations in subsequent power exercises**.** Values obtained in CE-UL in UL at minute 5 could have confirmed this fact. Meanwhile fast exercises after applying the load could contribute to activate the neural component of fast movements as was observed in the rest of protocols at minute 8. This is supported on studies which tested the effects of dynamic contractions in dynamic activities, showing better results than those who tested isometric conditioning exercises in dynamic actions [2, 20, 31]. The speed of a movement is always the result of the produced acceleration impulse. Squat Jump and Jumping push up were not maximal activities, but them could have easily represented a percentage between 65%-80% of such a maximum, especially in women. This load still allowed the subject to include a flight phase, only possible by a high speed on the movement. Allowing favorable neural adaptations occurring during the ensuing faster power exercises [2, 12].

According EMG values, in LL, results obtained in RF and VL kept stable on the first stages of the test in CE, CE-L and CE-U, showing a decreasing trend of electrical activity especially between minutes 8 to 12. However, this trend not achieved statistical significance in almost any cases (Figure 4.4). In CE-L, it caught our attention not reaching significance in RF despite of an electrical activity losing about 11% between jumps performed at minutes 8 and those performed at minute 12. Nevertheless, an statistical deterioration was found in VL at the same stage in CE-L ($F_{4,11} = 3.308$, $p = 0.05$), supporting the fact that EMG is not able of being maintained high from that minute onwards. When EMG in UL muscles was studied, no differences were detected for TB and PM neither in CE, CE-L or CE-U, and values kept relatively stable along the test (Figure 4.5).

That was not the case on the combinated protocol CE-UL. Since EMG values in LL showed an increasing trend after load application (Figure 4.4), not statistically significant though. And a similar variation was found for UL in EMG acquired in TB**.** On this case, significance was found (EMG: 1.13 ± 0.084mV, $p = 0.046$), and such variation was observed when load was specifically applied on arms. Which give us evidence that load could produce an acute effect on such EMG values immediately after applying a heavy load (Figure 4.5). However, is important to note that in none of those increasing values collected in EMG, the highest impulse was achieved. Therefore, this could establish EMG as a no dependant factor of high performance.

This idea was supported when results were split into gender, since some negative correlations confirmed the aforementioned fact found between impulse and EMG. These relations showed that subjects with high EMG values, also showed low values in impulse. These relations were very heterogeneous and the most part of them were not really strong, only revealed by Spearman’s coefficient. But is important to consider this fact as the reason behind some of the studies which failed in showing a relationship between excitability and performance [15]. As an example, in CE and CE-UL, EMG values in LL were close to show negative significance in males after Spearman’s analysis, especially at pretest and at minute 5, showing high EMG in RF related with low impulse in LL. Unexpectedly, this relation became inversely along the test and as soon as EMG values reached a decreasing trend, LL impulse values were registered higher. Such a relation was repeated in CE-L in females and significance on such relationships was found at pretest, at minute 8 and 12. And the lower the EMG showed, represented the highest impulse achieved. However, no relations were found at minute 5, the consecutive stage after load application because EMG values maintained relatively high when impulse was registered. On the other hand, values obtained for TB in males in CE-UL at minute 5 were close to be significantly positive by Spearman’s coefficient, expressing that high EMG values were related with high values of impulse ($r = 0.762$, $p = 0.058$), and although it was only a trend and impulse did not improve, it establish a contradictory pattern of interpretation. Thus, more research is needed for clear this fact. Maybe this is a question of fast units’ involvement and therefore there is little or no benefit of increasing the general recruitment of the whole muscle [30], but as similar to the force/time relationship of the impulse theorem, it might exist a relationship between the intensity of the EMG and the duration of such a signal. High intensity values achieved in EMG could not represent maximum EMG average if those values are applied during a short time. In any case, this study presented limitations regarding the interpretation of EMG. In spite of being highly related with the gesture, only two muscles, both in lower and upper limbs were analyzed. Therefore, results obtained would be conditionated to the interpretation of the results in these two muscles. Other synergist muscles are activated during voluntary contractions and contribute to maximal force and shape of the load-velocity relation [4, 5, 18].

This study tried to observe a relationship between a load applied on Lower or Upper limbs and their subsequent influence on the same limb and also in contrary. Changes happened in limbs after specific load application, but no influences were found when load applied in such limb was assessed in the other. When load was applied on legs, them showed variations in impulse and EMG as a consequence of that load. When such a load was applied on arms, them reacted in a same way than legs. But them did not receive any influence from each other, so the hypothesis that PAP could produce a systemic effect was refused. This is in agreement with the physiological explanation of PAP previously theorized for some authors [4, 5, 28, 34, 35]. The regulatory light chain of myosin (RLC) is phosphorylated in striated muscles by Ca2+/calmodulin-dependent myosin light chain kinase. Since Ca2+ joins to Troponin C it produces a rotation of the Tropomyosin, releasing in actin filament the active binding sites where myosin is attached. Ceiling effect of Ca2+ concentration is also reported after conditioning contraction [4, 5]. That is one of the reasons that myofibers become more sensitive. This phosphorilation, produces a movement of the myosin head better positioned for a new actin molecule attachment. Once Pi is released, the cross bridge attachment become stronger and better prepared for the strength development and this process is believed to last until 4 or 5 minutes later [33]. As more phosphorilation ensures more myosin heads are moving away from the thick filament, more cross bridges are able of being attached, and in a better way [21]. Generating a higher sliding of the actin filament to center of the sarcomere, and therefore, more strength [18]. Unique biochemical and cellular properties of this phosphorylation system in fast-twitch skeletal muscle maintain RLC in the phosphorylated form for a prolonged period after a brief tetanus or during high intensity/low-frequency repetitive stimulation, as is obtained with a heavy load [34]. Therefore, phosphorylation correlates with potentiation of the rate of development and maximal extent of isometric twitch tension [33]. Is important to note, that ATP is necessary in all the attachment/detachment process, being necessary to wait until 3-4 minutes for having it completely restored [21]. To the best our knowledge, the important fact is being able of waiting until ATP is restored and developing the contraction when myofiber cells are still phosphorilated. In other words, competitive tasks should be performed when fatigue is already dissipated and potentiation effect still remains.

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CHAPTER V

- EFFECTS OF TWO TYPES OF ACTIVATION PROTOCOLS BASED ON POST-ACTIVATION POTENTIATION ON SWIMMING START PERFORMANCE.

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ABSTRACT

Introduction: It was aimed to compare the effects of two protocols of postactivation potentiation method (PAP) on swim start performance (SS). ***Methods:*** Fourteen aged trained swimmers (10 men and 4 women) volunteered in this study. An intra-group design of randomized repetitive measurements was applied. Initially, a previous SS trial served as reference and was performed after a standard warm up (SWU). After one hour of rest, two methods of PAP were randomly added to the SWU: i) three lunges at 85% of 1 repetition maximum (LWU), and ii) four repetitions on the flywheel device: YoYo Squat (YWU). Swimmers were tested in a SS eight minutes after the warm ups. Kinematic variables were collected using three digital video cameras fixed on the poolside operating at 25 Hz and one high speed camera focused to the block operating at 300Hz. The obtained data from the video-analysis were processed using a repeated measures analysis of the variance. ***Results:*** Results revealed an improvement of the horizontal velocity during the flight (HxV) after both PAP methods, but specially after YWU ($F_{2,12} = 47.042$, $p < 0.001$) ([HxV] SWU= 3.63 ± 0.11 vs. LWU= 4.15 ± 0.122 vs. YWU= 4.89 ± 0.12 m/s) . After YWU, it took the subjects less time to cover a distance of five meters (T5m) ($F_{2,12} = 24.453$, $p < 0.001$) and fifteen meters (T15m) ($F_{2,12} = 4.262$, $p < 0.04$). Subjects also achieved a higher mean angular velocity of the knee extension VωK ($F_{2,12} = 23.286$, $p < 0.001$) and a reduction of the time on the block (BT) ($F_{2,12} = 6.595$, $p < 0.05$). ***Conclusion:*** These values indicate an enhancement of the muscle performance in the execution of a SS after a warm up with specific PAP stimulus. In view of the results the application of YWU improves the performance of the swimmer's start and therefore may be especially relevant in short events.

KEY WORDS: Flywheel, Warm up, PAP, Dynamic Stretching, OSB11 Block

RESUMEN

Introducción: el objetivo fue comparar los efectos de dos protocolos de potenciación post-activación (PAP) en el rendimiento de la salida de natación (SS). ***Método***: Catorce nadadores entrenados (10 hombres y 4 mujeres) se ofrecieron como voluntarios en este estudio. Se aplicó un diseño intragrupo de medidas repetitivas. Inicialmente, se realizó una salida de natación después de un calentamiento estándar (SWU) y sirvió como referencia. Después de una hora de descanso, se volvió a realizar el protocolo SWU al que se añadieron aleatoriamente dos métodos de PAP: i) tres zanzadas al 85% de 1 repetición máxima (LWU), y ii) cuatro repeticiones en una máquina de entrenamiento excéntrico: YoYo Squat (YWU). Los nadadores fueron evaluados en una SS ocho minutos después de los calentamientos. Las variables cinemáticas se obtuvieron usando tres cámaras de video digitales fijadas en la piscina operando a 25 Hz y una cámara de alta velocidad enfocada al poyete que operó a 300Hz. Los datos obtenidos del videoanálisis se procesaron utilizando un análisis de la varianza de medidas repetidas. ***Resultados:*** los resultados revelaron una mejora de la velocidad horizontal durante el vuelo (HxV) después de ambos métodos PAP, pero especialmente después de YWU (F2,12 = 47.042, p <0.001) ([HxV] SWU = 3.63 ± 0.11 vs. LWU = 4.15 ± 0.122 vs. YWU = 4.89 ± 0.12 m / s). Después de YWU, les tomó a los sujetos menos tiempo cubrir una distancia de cinco metros (T5m) (F2,12 = 24.453, p <0.001) y quince metros (T15m) (F2,12 = 4.262, p <0.04). Los sujetos también lograron una mayor velocidad angular media de la extensión de la rodilla VωK (F2,12 = 23.286, p <0.001) y una reducción del tiempo en el bloque (BT) (F2,12 = 6.595, p <0.05). ***Conclusión:*** Estos valores indican una mejora del rendimiento muscular en la ejecución de una SS después de un calentamiento con estímulo PAP específico. En vista de los resultados, la realización de las repeticiones en la máquina de entrenamiento excéntrico parece mejorar el rendimiento del nadador en la salida y, por lo tanto, puede ser especialmente relevante en las pruebas de velocidad.

INTRODUCTION

Swimming start performance (SS) is an important component of the swimming race, especially in short events [8]. It consists of explosive movements intended to impulse a swimmer from the starting block to water [9, 42]. Among male elite swimmers, swimming velocities are around 1.8 to 2m/s, while the typical average velocities over the first 15m of the race are around 3m/s. The shorter is the distance of the race, the higher is the repercussion of the final result, and these values ranges between 10-30% of the final result in 50 and 100 meters distance [8]. Therefore, if wanting to take the maximum advantage of that percentage, it is required a good pre-activation that prepares the lower body in the best conditions [5, 17, 35, 43].

To date, there are a few number of studies that examined the SS performance using different types of warm-up, and those that exist, are conducted with a lack of specific stimulus for the lower limbs of the subjects [3, 9, 23]. Moreover, to author's knowledge, there is no any study where this issue is assessed on the new block, where the legs have an asymmetric placement. Therefore**,** it is necessary to find some asymmetric potentiation exercises in order to provide a more specific and stronger stimulus: one of them might be the "Lunge" exercise, which primarily activates the hip and knee extensor musculatures of the front leg [11, 20], and it causes the biggest impulse in track start [19]. On the other hand, may be interesting to draw on inertial systems to induce potentiation as the flywheel inertial device YoYo Squat (YoYo™ Technology AB, Stockholm, Sweden), because has been reported for many authors a very high muscular activation in EMG studies [11, 24, 25, 26, 41]. A potential benefit of flywheel inertial devices is that the resistance is independent of the gravity. As such, resistance can be applied from any direction, what allows a wide variety of exercises [11, 25, 26, 27, 41]. Particularly, due to it is necessary be attached to a belt that emerges directly from the device, the system allow to apply a potentiation gesture almost the same as the real forward extension movement that the swimmer has to perform on the block, avoiding falls.

Therefore, the aim of this investigation was to compare the effects of two activation protocols for lower limbs on the variables affecting the swimming start. It was studied two specific ways of inducing PAP in the warm up, such as: maximum repetitions in Lunge exercise and, maximum repetitions in YoYo Squat flywheel inertial device. And these two methods were compared to an standard warm up method. We hypothesized that an activation protocol with the

PAP inducement by using the flywheel inertial device would be the most appropriate warm up for performing a swimming start in the best condition.

METHODS

Experimental Approach to the Problem

A repeated-measures counterbalanced design was used in which swimmers performed two different activation protocols before performing a SS after eight minutes of rest. Firstly, all participants performed a SS after a standard warm up (SWU), consisting of a varied swimming warm up followed by dynamic lower limb stretching. This protocol was considered the control situation. After that, swimmers were randomly separated in two groups, the first one performed the first activation protocol (LWU) consisting of the realization of SWU followed by PAP inducement through 1 set of 3 “Lunge” repetitions at 85% 1RM; the second group performed the second activation protocol (YWU) consisting of the realization of SWU followed by PAP inducement through 1 set of 4 repetitions at maximal voluntary contraction on the YoYo Squat flywheel device. Later, that group order was reversed in order to avoid the “fatigue/learning” effect. Three tests were carried out with one hour break.

Subjects

Fourteen trained swimmers (10 men and 4 women), members of swimming clubs of Granada (Spain), between 17 and 23 years of age, (height 176.3 ± 9.1 cm; weight 69 ± 11.4 Kg.), from whom written informed consent and parental approval had been obtained, volunteered to take part in this study after being informed of all risks, discomforts and benefits involved. The study was approved by the university ethics committee. Swimmers were recruited on the basis that they were federated swimmers with at least 5 years of participation in National competition.

Prior to the study, each participant was pretested in the pool in time to 15 meters, and visited the laboratory to become familiar with the testing methods and to have their 3RM Lunge measured (values 77.1 ± 23.4 kg). During this familiarization session, swimmers also practiced on the flywheel inertial device the characteristic forward extension movement of the SS performance**.**

Procedures

Prior to data collection, all subjects attended three trials sessions on the YoYo Squat flywheel inertial device. In these sessions, the RM values for the Lunge were also obtained in a Multi-Power according to the guidelines set by National Strength and Conditioning Association [20]. In these sessions, swimmers gave their informed consent, and all anthropometric measures were taken. These training sessions were conducted in the Physical Education and Sport Department, University of Granada (Spain), which is equipped with a Multi Power device. The experimental setting was the Olympic pool of High Altitude Training Center, National Sport Council (Sierra Nevada) in the city of Granada (Spain), which is equipped with the OSB11 block and the flywheel inertial device.

Swimmers reported to the experimental setting on the morning of testing after having refrained from alcohol, caffeine, and strenuous exercise for the previous 48 hours. After a standardized meal and fluid intake, they had to perform three warm ups, all of them in the morning, between 9:00 and 15:00, with a break of an hour between each of them. During the whole session, the swimmers were allowed to drink water.

On arrival, reference points were marked on the joints of the hip, knee and ankle. Subsequently, the swimmers were accurately informed about the testing day; each time the swimmers had a warm up protocol, they had a rest period of 8 minutes to perform a competition SS at maximum intensity. There was only one performance for each test in order to simulate the conditions of competition "an attempt". During the whole session there was a collaborator who controlled the resting time for each subject. The output signal was an auditory stimulus, in this case the one applied in competitions. In each trial, the subject was requested to mount the block. When in position, the subject was given the verbal command “take your mark”, and shortly afterwards the starting signal was sounded. After recording the trial, swimmers rested for an hour.

First, all swimmers performed the standard warm up (SWU), which consisted of varied swimming warm up followed by dynamic lower limb stretching. The warm up included 400m of varied swimming, consisting of: 200 meters easy freestyle swim, performing two starts from the wall (one of them to get into the water, and the other after 100 meters.); 1 x 50 m front crawl swim (12’5 fast/ 12’5 smooth); 1 x 50 m front crawl swim at race pace; And another 100 meters front crawl swimming at a normal pace. In order to establish a time interval between one swimmer and the next, each swimmer was asked to begin the warming up when the swimmer that preceded him or her, was performing the second SS of the first 200 meters of the warming up, this provided a higher methodological control for evaluators. After swimming, the participants got out of the water and began their dynamic stretching protocol, which consisted of: forward leg swings, ankle dorsi/plantar flexion, side leg swings, high knees, heel flicks, squat and lunge. Each exercise was performed 10 times, and the entire series was repeated twice (1 series per min.). Dynamic stretches were designed to have an effect on the musculature most closely related to jump performance. During the whole stretching set, there was a collaborator who controlled that stretching was performed properly and at the right pace during 4 minutes. After 8 minutes of rest, the swimmers performed a SS.

Secondly, swimmers were randomly halved in two groups of 7 people each. The first group performed the warm up with Lunge repetitions (LWU), which consisted of warming and dynamic stretching as in SWU, to which the PAP stimulus was added through the realization of the exercise Lunge in a “Multi power” device (Figure 5.1). The position of the exercise was controlled according to the rules of the National Strengh and Conditioning Association [20]. The initial position consisted of the rear knee placed on a lifted surface at 5 cm from the ground, in order that the leg and thigh formed a 90 degrees angle, similarly, the foot of the front leg placed on its entire surface to the ground so that the leg and thigh also formed a 90 degree angle. Once this position was set, the extension of the legs was performed. Swimmers were asked to place their legs in the same position that they used to perform the swimming starts, in order to keep a control about which leg was placed front or behind. All subjects had to perform three repetitions at maximum speed to 85% of 1RM. During the whole exercise, there was a collaborator who controlled the initial position and the specific loads of each subject. After 8 minutes of rest, swimmers performed a swim start. The second group, performed the warm up with repetitions in YoYo Squat flywheel device (YWU), which consisted of warming up and dynamic stretching as in SWU, to which the PAP stimulus was added through repetitions on the “YoYo Squat” flywheel device (Figure 5.2). The initial position consisted of the same position that it is performed by swimmers on the block, with the same front/behind placing of legs. Once the belt was attached, swimmers performed 4 maximum intensity repetitions. The reason for the election of 4 repetitions was that the first repetition serves to charge the flywheel. During the whole exercise, there was a collaborator who controlled the initial position and provided to swimmers device harnesses. After 8 minutes of rest, the swimmers performed a SS.

To carry out the third trial, the order was reversed, the first group performed YWU and the second group performed activation protocol LWU. Similarly, after 8 minutes of rest, swimmers performed a SS.

Figure 5.1. PAP Induction through the Lunge Exercise

Figure 5.2. PAP Induction through executions on the YoYo Squat flywheel device

Kinematic Measurements

Dive Distance (DD).The distance from the swimming pool wall under the starting block to the first contact of the swimmer's fingers with the water (in centimeters).

Flight time (FT).The time between the last contact of the feet with the starting block and the first finger contact with water (in seconds).

Horizontal Hip Velocity (VxH). The horizontal hip distance during the flight, from the last contact of the feet with the starting block to the first finger contact with water, divided by the time elapsed for this action (in meters per seconds).

$$VxHip = \frac{\mathrm{x}}{\mathrm{t1} - \mathrm{t0}}$$

Time to 5 meters (T5m). The time since flash lights out until the head touches the baseline at 5 meters.

Time to 15 meters (T15m). The time since flash lights out until the head touches the baseline at 15 meters.

Block Time (BT). The time since flash lit up until the moment in which the swimmer is separated from the block.

Angle of Take-off (AT). The angle between the horizontal line and the line which connects the body’s center of mass with the referential spot on the foot, at the moment of the last contact of the foot with the starting block (in degrees).

Angle of Entry (AE). The angle between the horizontal line and the line which connects the body’s center of mass with the referential spot on the hand, at the moment of the first contact of the fingers with the water (in degrees).

Angular Velocity of Knee Extensión (VωK) The knee’s angular difference between at the moment of maximum extension and the moment of “ready” (maximum flexion), divided by the time elapsed for the performance of that extension.

$$V\alpha = \frac{\mathrm{\alpha 1} - \mathrm{\alpha 0}}{\mathrm{t1} - \mathrm{t0}}$$

Data collection for swim Starts. Each trial was recorded with four digital video cameras; one of them was a high speed camera (Casio, HS Camera 300Hz) operating at a sampling rate of 300Hz; it was mounted on a tripod and focused to the block. This camera recorded the BT, AT and VωK. The three other digital video cameras (Sony Video Camera, 50Hz) were fixed on the poolside. One of them registered the block phase, another one registered the underwater phase to 5m and the last one registered the swim phase until 15 meters. The three sequences were overlapped in space and time by a video switcher (Digital Video Switcher SE-900). These cameras recorded the DD, FT, VxH, AE, T5m and T15m. The shutter speed was adjusted using a modality (Sport Mode) that maximized the shutter speed within the limits of the cameras being used (1/4,000 seconds), consequently minimizing any distortion within the movement of the swimmers. Both block cameras were focused on the starting system to spot the light emitted by the starting signal. The starting system (Signal Frame, Sportmetrics) simultaneously emitted an audible signal and a strobe flash; this was used to synchronize the starting signal with the video image. All video files registered were analyzed by two different researchers who used the software Kinovea®, version 0.7.10., this software allowed an accurate analysis of the reference points drawn on swimmers.

Statistical Analysis

Statistical analysis was performed using SPSS Version 21.0 (IBM, Chicago, IL, USA). After testing for the normality distribution, analysis was carried out using a repeated measures ANOVA to determine differences within and between subjects concerning the three protocols applied. To detect difference between protocols, significance was accepted at the *alpha* < 0.05 level and paired comparisons were used in conjunction with Holm's Bonferroni method for a control of the type 1 error.

Descriptive statistics were calculated and data were expressed as the mean ± SD and the confidence interval. The test-retest reliability (intraclass correlation [ICC]) within and between observers was analyzed for the all variables.

Six trials, three of them digitized by the researcher and the other three by an investigator with experience in digitization management of the Kinovea® software, were quantified using intra-class correlation coefficients (ICC) in order to assess the reliability of the digitizing (intra, inter-observer). These correlations were calculated separately for the repeated measures of all the variable values of, 6 randomly chosen subjects. The intra-observer ICC ranged from 0.97 (95% confidence interval (CI) 0.96-0.98) to 0.99 (95% CI 0.98-0.99); and the inter-observer ICC ranged from 0.98 (95% CI 0.97-0.98) to 0.99 (95% CI 0.99-0.99). These results showed a high correlation and reliability.

RESULTS

All data of the variables studied are shown in Table 5.1 with mean, standard deviation and confidence interval.

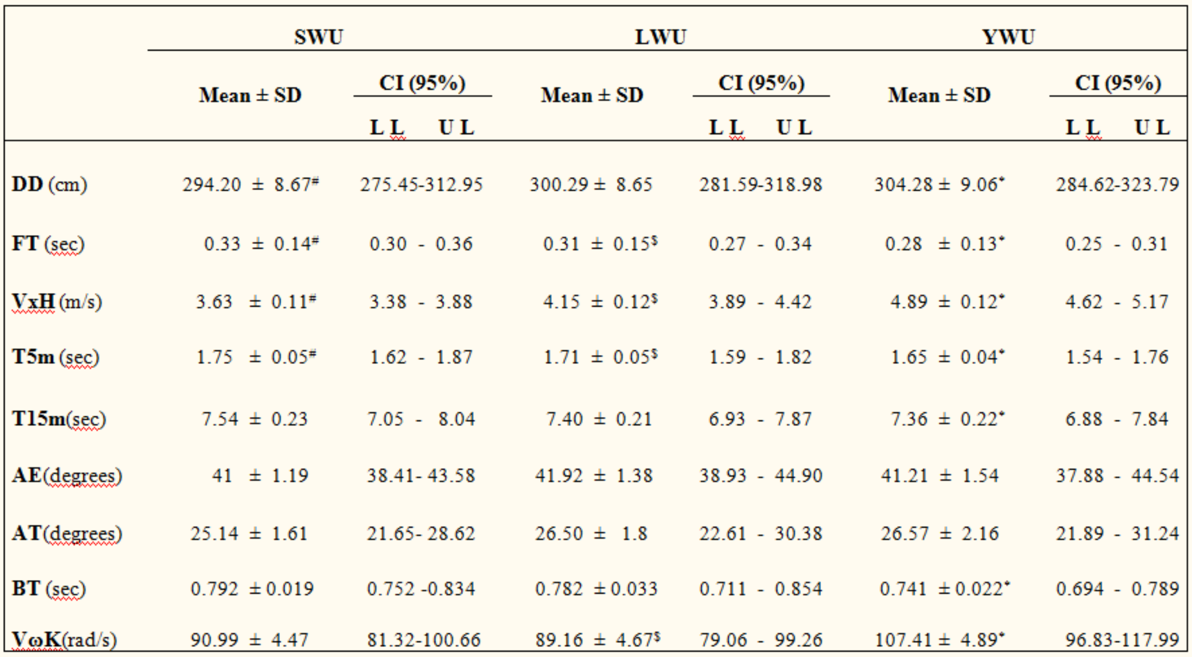
The repeated measures ANOVA analysis revealed significant differences for DD ($F_{2,12} = 35.861$, $p < 0.001$) among the three warm up protocols, being highly significant after protocols with PAP inducement ($p < 0.01$) compared to the control situation. The distance of entry in the water was longer for YWU (304.28 ± 9.066 cm) and LWU (300.29 ± 8.654 cm) in comparison with SWU (294.2 ± 8.679 cm). We also found significant differences in FT ($F_{2,12} = 69.491$, $P < 0.001$) after YWU ($p < 0.001$) compared to SWU, and after YWU compared to LWU ($p < 0.01$), with shorter mean times for YWU (0.28 ± 0.13 sec) and LWU (0.31 ± 0.14 sec) compared to SWU (0.33 ± 0.14 sec).

The mean values registered for VxH (during flight) revealed significant differences among the tree warm up protocols ($F_{2,12} = 47.042$, $p < 0.001$). They showed that swimmers were faster during flight after the activation protocol YWU (4.89 ± 0.12 m/sec) compared to the two others (Table 5.1). The VxH was also higher ($p<0.001$) after LWU (4.15 ± 0,122 m/sec) compared to SWU (3.63 ± 0.11 m/sec).

For T5m, differences were found among the three warm up protocols ($F_{2,12} = 24.453$, $p < 0.001$), being higher for comparisons between YWU and SWU ($p < 0.001$) and P1 ($p \leq 0.001$) as it the time mean were shorter for YWU (1.65 ± 0.052 sec), compared to LWU (1.71 ± 0.053 sec) and both shorter compared to SWU (1.75 ± 0.057 sec). Comparisons between LWU and SWU also revealed a significant differences ($p = 0.03$). However, for T15m, we only found significant differences ($F_{2,12} = 4.262$, $p < 0.04$) between YWU and SWU, with mean values of 7.54 ± 0.23 sec after SWU, and mean values of 7.36 ± 0.22 sec after YWU ($p < 0.05$).

Differences were found for BT ($F_{2,12} = 6.595$, $p < 0.05$). However, pair comparisons only revealed differences between SWU and YWU ($p < 0.05$), with shorter mean values registered after YWU (0.741 ± 0.022 sec) compared to mean values after SWU (0.792 ± 0.019 sec). No difference were found for AE ($F_{2,12} = 0.246$, p = not sig.) and AT ($F_{2,12} = 0.457$, p = not sig.) after the three warm up protocols (Table 5.1).

Statistical analysis for VωK revealed significant differences between protocols ($F_{2,12} = 23.286$, $p < 0.001$). These differences were significant after the protocol consisting of the flywheel's execution (YWU) compared to SWU ($p < 0.005$) and also compared to the mean values after LWU ($p < 0.001$), being highest the knee extension velocity mean values obtained for YWU (107,41 ± 4,89 rad/sec) in comparison with the two other warm up protocols (Table 5.1).



	SWU		LWU		YWU	
	Mean ± SD	CI (95%) L L U L	Mean ± SD	CI (95%) L L U L	Mean ± SD	CI (95%) L L U L
DD (cm)	294.20 ± $8.67^{\#}$	275.45-312.95	300.29 ± 8.65	281.59-318.98	304.28 ± 9.06^{*}	284.62-323.79
FT (sec)	0.33 ± $0.14^{\#}$	0.30 - 0.36	0.31 ± $0.15^{\$}$	0.27 - 0.34	0.28 ± 0.13^{*}	0.25 - 0.31
VxH (m/s)	3.63 ± $0.11^{\#}$	3.38 - 3.88	4.15 ± $0.12^{\$}$	3.89 - 4.42	4.89 ± 0.12^{*}	4.62 - 5.17
T5m (sec)	1.75 ± $0.05^{\#}$	1.62 - 1.87	1.71 ± $0.05^{\$}$	1.59 - 1.82	1.65 ± 0.04^{*}	1.54 - 1.76
T15m(sec)	7.54 ± 0.23	7.05 - 8.04	7.40 ± 0.21	6.93 - 7.87	7.36 ± 0.22^{*}	6.88 - 7.84
AE(degrees)	41 ± 1.19	38.41- 43.58	41.92 ± 1.38	38.93 - 44.90	41.21 ± 1.54	37.88 - 44.54
AT(degrees)	25.14 ± 1.61	21.65- 28.62	26.50 ± 1.8	22.61 - 30.38	26.57 ± 2.16	21.89 - 31.24
BT (sec)	0.792 ±0.019	0.752 -0.834	0.782 ±0.033	0.711 - 0.854	0.741 ±0.022^{*}	0.694 - 0.789
VωK(rad/s)	90.99 ± 4.47	81.32-100.66	89.16 ± $4.67^{\$}$	79.06 - 99.26	107.41 ± 4.89^{*}	96.83-117.99

Table 5.1. Mean, standard deviation and confidence interval of spatio-temporal and angular variables in the three different activation protocols (n=14).

DISCUSSION

The aim of this investigation was to compare the effects of two activation protocols for lower limbs on the variables affecting the swimming start. It was studied two specific ways of inducing PAP in the warm up, such as: maximum repetitions in Lunge exercise and, maximum repetitions in YoYo Squat flywheel inertial device. And these two methods were compared to an standard warm up method. We hypothesized that an activation protocol with the PAP inducement by using the flywheel inertial device would be the most appropriate warm up for performing a swimming start in the best condition and the results indicated an enhancement of the muscle performance after YWU.

Two activation protocols were added to the standard warm up in order to improve the SS. According some authors [5, 17, 35, 43], this activation should be mainly applied to the lower limbs because in several studies in elite swimmers, a clear relationship between the propulsive actions of the legs with a good performance in SS has been demonstrated. The first protocol (SWU) was established as a control situation and consisted of standard warm up composed of varied swimming, followed by dynamic lower limb stretching. This protocol was based on the improvement of the performance after physical warming, previously shown by many authors [3, 6, 7, 24, 30], and in the realization of dynamic stretching protocols in order to improve range of motion and explosive executions [4, 10, 30, 34, 38]. We decided to combine both aspects to provide specific stimuli, thereby enhancing the effects achieved in the warm up as previously noticed by Fletcher, (2010)[16] and Samson, (2011)[34].

In LWU, the swimmers performed the same warming up as in SWU but then, the PAP was induced through a Lunge at 85% of 1RM. This protocol was based on the study of Kilduff et al., (2011)[23], which compared the effect of a warming up and the effect of an activation protocol based on PAP on swimming starts. In that study, the authors found similar results after warming up and after PAP but they did not investigate whether the adherence of PAP to warming up would be able to cause a bigger potentiation stimulus or contrary, whether potentiation would be exceeded by the generated fatigue. Till and Cooke (2009)[39], had previously found that their participants did not react to the PAP because they were not able to recover after the PAP stimulus. In this case, the load was strong enough for them to cause activation, however the short time of rest did not allow the fatigue to dissipate. Thereupon, both aspects have been considered in our study trying to provide load and rest enough. On the other hand, in the study of Kilduff et al., (2011)[23], PAP was induced by the exercise “Squat” at 87% of 1RM, while in our study, PAP was induced by the exercise “Lunge”. This decision was taken in order to provoke on lower limbs a stimulus biomechanically similar to the real action [15], but considering the use of a free weight exercise as in the study of Kilduff et al., (2011)[23]. With this exercise, the front leg is mainly potentiated due to the asymmetry of the legs placement [11], and according to the asymmetry study of leg collocations carried out by Hard et al., (2009)[19], the front leg causes the biggest impulse in track start.

In YWU, the swimmers performed the same warming up as in SWU and subsequently PAP was induced through four repetitions on the YoYo Squat. The application of this activation system was an innovative aspect of our study because we have not found any references to its use in swimming. It was based on two clear objectives: taking advantage of the characteristic of the system for executing an activation gesture almost identical to the real action [15], without any risk of falls; and generate from the first rep of each set a high lower limb activation due to the high requirements of power and strength in most concentric and eccentric phases [11, 25, 26, 27, 41]. It is common to find in the literature many studies where the load is applied in accordance with a previous test of RM. However, in the whole process subjects may vary their performance either for a deterioration or an improvement of their skills, or even because the load was no obtained properly. With the use of YoYo Squat, this problem is resolved because the resistance is proportional to the force applied. Hence, the subject is able to perform his maximum regardless the individual conditions the day of the test [11].

In order to assess the effectiveness of a swimming start, the analysis of the VxH is imperative because it expresses accurately the changes which occur in a swimmer’s performance in distance, time, or both. We observed that VxH ostensibly improved after YWU (4.89 ± 0.12 m/sec) compared to LWU and SWU (Table 5.1). This means that the swimmer’s flight was longer and faster, as confirmed by the increase of the values obtained for DD and by the reduction of the values obtained for FT (Table 5.1). In these variables, also an improvement after LWU compared to SWU for VxH ($p < 0.001$), DD ($p < 0.001$) and FT ($p = 0.004$) (Table 5.1) was obtained, which implies that activation protocols based on a PAP inducement caused positive effects on the participants during the first phases of the swimming start after take-off. Unfortunately, it was not possible to compare these data with those obtained by Kilduff et al., (2011)[23], because we applied different activation protocols and the variables registered were not the same, such as, the improvements that they obtained for horizontal and vertical peak forces after PAP application. However, it supposed that the results obtained in this study are clear evidence that an improvement of the peak forces occurred on the block. According many authors, PAP significantly improves peak forces due to the recruitment phenomenon caused by maximal or submaximal voluntary muscular contractions [10, 14, 22, 23, 33, 38, 40]. This causes an improvement in the velocity of the nerve's fiber conduction and an EMG activity increase. Subsequently in explosive gestures such as jumping or a SS, this means an increase in the height or distance, and jumping power. Furthermore, these results are in agreement with those obtained by Breed and Young, (2003)[9]. They assessed the effect of one specific resistance training focused on SS and found that the improvement of the strength applied onto the block was highly correlated with the improvement of the hip velocity during flight ($p < 0.05$).

T5m showed to be shorter after YWU application, as times registered at that point were lower than those registered for LWU and SWU (Table 5.1). We also observed slight differences ($p < 0.05$) between values obtained for LWU compared to SWU, in which PAP protocol seems to be better (Table 5.1). This means that the reduction obtained in the registered time was caused by the aforementioned enhanced flight phase [5]. The take-off potentiation provokes that swimmers enter into the water with more velocity and use it in the initial underwater gliding.

With regard to T15m, results revealed that the time was slightly decreased after YWU, thus it is possible to support the results previously obtained by West et al., (2011)[43] and Seifert et al., (2010)[35], where the best SS, defined as the time for 15 meters, were correlated with subjects with strong and powerful lower limbs because they were able to develop a high velocity at take-off. However, we only found significant differences between YWU and SWU ($p < 0.045$) (Table 5.1), but differences among LWU and the two others protocols were not remarkable. This could be caused for some reasons: one of them is that in swimming to 15 meters it is required to take into account other technical aspects as the power of the initial strokes or the effectiveness of undulatory swimming. For example, in the study of Elipot et al., (2010)[13], swimmers began the underwater kicks as soon as possible in order to gain speed. However, this provoked an increase of the drag and consequently a velocity loss. Another aspect could be that in this case, generated fatigue was higher than potentiation[39], being necessary more time of rest. Or contrary, which the load applied was insufficient. Thus, future studies should clarify this matter. In any case, these results from PAP application through free weight exercises were similar to those obtained by Kilduf et al., (2011)[23]. Although there is no worsening on T15m, there is no significant improvement after PAP stimulus induced through Lunge either.

Regarding block phases, the YWU application was remarkable compared to the two other protocols for mean values obtained for VωK and BT, because the results were better compared to the other activation situations. In the case of VωK the results revealed a better performance after the YoYo Squat warming up protocol (YWU vs. SWU, $p < 0.01$), (YWU vs. LWU, $p \leq 0.001$), as the velocity of the knee extension was higher than the two others protocols (Table 5.1), so the swimmers left the block before. These results are in agreement with those obtained by Yamauchi and Ishii, (2007) [44]. They studied the relations between force-velocity on vertical jump after a resistance training for lower limbs. They observed that the improvements gained in jump were caused by a higher extension velocity of the knee as a consequence of the improvement of the power generated. After YWU, the block phase of the swimmers was good because they were able to combine a short time on the block with a high force production [9]. This combination could be caused because the back leg was also potentiated with the executions in the YoYo Squat and, according to Arellano, (2010)[1], this leg provides a bigger impulse on the new block OSB11. For such low mean VωK values obtained after LWU (Table 5.1) has not been possible to conclude a clear explanation. In spite of vertical jumping has been commonly used for improve swimming starts, any studies have showed an improvement after vertical actions [5, 9, 31]. One reliable interpretation to this fact could be found in a recent study conducted by Rebutini et al., (2014)[31], where they found an improvement in the SS performance after a plyometric horizontal training, but no after plyometric vertical training. They concluded that the enhancements were caused by an increment in the rate of force development of the hip and knee due to the specific training. Therefore, this remarks that the enhancement of the general muscle performance is not enough for improving the overall performance, but the training of the specific skill is a key factor to achieve that goal because allow the control and training of the real resultant force vectors. On the other hand, it is possible that the initial angle of the front leg's knee of the swimmer were suboptimal for the proper force production. In the study of Slawson et al., (2012)[36], they showed that an optimal knee angle position should be fixed between 135 and 145 degrees for the front leg in SS. Possibly or subjects started with knee joint angles more open. Nevertheless, it may that the balance between fatigue and potentiation generated contains the key of this issue and should be attended in the future.

For BT, results revealed a reduction of the time on the block after YWU (0.741 ± 0.022 sec) compared to SWU (0.792 ± 0.019 sec). This may be the explanation for the dramatic improvement of VωK that we found in this study. The swimmers left the block before because the extension of their leg was faster. The results of BT after LWU did not show significant differences compared to the two other protocols (Table 5.1), although the mean values were not worse that those obtained in SWU. These results are in relation with those obtained for VωK after LWU. As there is no improvement in the velocity of the extension of the legs, there is no a reduction of the time of the block.

Regarding to AE and AT, these were not altered after any protocol application (Table 5.1). Consequently, we can assert that technical aspects have remained unchanged, thus improvements in performance can be explained by the influence of the different kinds of warm up or activation protocols on swimmers and not by a technical variation of the execution of the SS.

In conclusion, the purpose of this investigation was to compare the effects of two specific activation protocols based on the PAP phenomenon, such as: maximum repetitions in Lunge exercise and, maximum repetitions in YoYo Squat flywheel inertial device, on the variables affecting the SS. In view of the results, the protocols which included a specific PAP application showed better results than the standard warm up. Specifically, the application of flywheel inertial device (YWU) would be the most appropriate warm up for performing a swimming start in the best condition because improves the performance on SS and therefore may be especially relevant in short events.

PRACTICAL APPLICATIONS

The relevance of our study is the application of a system used in explosive gestures in the field of aquatic sports such a swimming start performance, which has been observed to improve the performance of swimmers, especially in short events. The effect on start time or the increase of angular velocity of knees leads us to recommend the application prior to competition in short events. The optimum performance occurs when the fatigue has dissipated and the enhancement still exists; therefore, improving the fatigue resistance should be an important task for coaches because may allow greater enhancement effects after PAP. However, the adaptation of methods to competitive constraints should be resolved in the future. Its application to improve the power application during the first strokes pulling seems an interesting subject to be studied in the near future.

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CHAPTER VI

- RELATIVE FORCE AND PAP IN SWMMING START PERFORMANCE

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ABSTRACT

Introduction: PAP benefits are more effective when including a rest period of 6-8 minutes after a submaximal stimulus application or when it is applied to trained subjects or individuals with a high proportion of fast fiber. However, comparisons are not possible if is unknown a value of that state of training. ***Methods:*** Firstly, it was studied the relationship between relative force (Frel) of the lower limbs in a isotonic Lunge test, with the performance in a swimming kick start (SS). Afterwards, were applied two Postactivation-Potentiation (PAP) specific warm ups in order to analyze their effect in performance considering the F_{REL} of the subjects. Trained swimmers (n=14) volunteered in this study. *Pearson* product-moment correlation coefficients were used to verify the relationship between relative force and kinematic variables of a SS. ***Results:*** Results revealed high correlation between relative force and performance in SS (Dive Distance: R2=0.872, p<0.001; Horizontal Hip Velocity: R2=0.308, p=0.049; Time to 15m: R2=-0.813, p<0.001). ***Conclusion:*** After PAP, swimmers with higher relative force showed a higher improvement on the kinematic variables of SS than those with lower values of strength.

KEY WORDS: Warm-Up, swimming starts, PAP, YoYo Squat flywheel device.

RESUMEN

Introducción: los beneficios de la potenciación post-activación son más efectivos cuando se incluye un período de descanso de 6-8 minutos después de la aplicación de un estímulo de intensidad alta o cuando se aplica a sujetos entrenados o individuos con una alta proporción de fibra rápida. Sin embargo, las comparaciones no son posibles si se desconoce el valor de ese estado de entrenamiento. ***Método:*** En primer lugar, se estudió la relación entre la fuerza relativa (F_{REL}) de los miembros inferiores en una prueba de zancada isotónica, con el rendimiento en una salida de natación (SS). Posteriormente, se aplicaron dos calentamientos específicos de Potenciación post-activación para analizar su efecto en el rendimiento considerando el F_{REL} de los sujetos. Catorce nadadores entrenados (n = 14) se ofrecieron como voluntarios en este estudio. Se usaron los coeficientes de correlación producto-momento de Pearson para verificar la relación entre la fuerza relativa y las variables cinemáticas de un SS. ***Resultados:*** Los resultados revelaron una alta correlación entre la fuerza relativa y el rendimiento en SS (Distancia de zambullida: R2 = 0.872, p <0.001; Velocidad de cadera horizontal: R2 = 0.308, p = 0.049; Tiempo hasta 15m: R2 = -0.813, p <0.001). ***Conclusión:*** Después del PAP, los nadadores con mayor fuerza relativa mostraron una mejoría mayor en las variables cinemáticas de SS que aquellos con valores de fuerza más bajos.

INTRODUCTION

With the new starting blocks Omega (OSB11, Corgémont, Switzerland), block time is shorter than the time achieved with the old starting platforms [4]. However, results found in the recent literature show that it is preferable to achieve a good impulse adopting a rear weighted position, which implies higher muscle implication [1], than to try to get off the platform as quickly as possible [6]. Some studies have shown the relationship between lower body muscle force and swimming start performance (SS)[2, 9] and the results suggests that swimmers who possess greater maximum force and specific rate of force development at absolute and relative levels, tend to be able to swim faster on initial meters of SS [2, 9].

Such relationship has lead the interest of some authors for optimizing the take-off parameters of a SS, providing specific warm up routines related to Postactivation Potentiation (PAP) method [3, 5]. PAP improves muscle contractility, in strength and speed, by having previously applied a combination between near maximal loads with an optimal recovery time after such conditioning activity. Some studies have confirmed this issue in lower limbs through an assessment of the performance during the recovery period and the results concluded that PAP benefits are more effective when including a rest period of 6-8 minutes after a submaximal stimulus application [3, 5, 8]; when it is applied to trained subjects or individuals with a high proportion of fast fiber because they are considered individuals better prepared or accustomed to overcome the fatigue [7, 8]; and, when the gesture to cause potentiation is biomechanically similar to the real movement, because the empowerment obtained is more specific and intense in the muscles involved [7, 8].

However, comparisons are not possible if is unknown a value of that state of training. In this study we offer the relative force (F_{REL}), as a way of obtaining such categorization. The purpose of this study was twofold. The first aim was to evaluate the relationship between lower limbs Frel values obtained through a Lunge test and performance on a SS. To author’s knowledge, no studies assesses this issue considering the asymmetric characteristics of the new block. The second aim was to evaluate such relationship after the application of two specific PAP protocols. If more strong individuals are considered to perform a swimming start in better conditions and PAP is more effective in trained athletes, it supposed that best trained swimmers would be able to react better after PAP application and perform a swimming start with better guarantees than weaker athletes.

METHODS

Subjects

Fourteen trained swimmers (10 men and 4 women), with at least 5 years of participation in National competition, members of swimming clubs of Granada (Spain), between 18 and 23 years of age, (height 176.3 ± 9.1 cm; weight 69 ± 11.4 Kg.), from whom written informed consent had been obtained, volunteered to take part in this study.

Procedures

Prior to the study, each swimmer visited the laboratory in order of collecting their strength values. Initially, they performed a repetition maximum (RM) isotonic Lunge test (values 68.84 ± 25.19 kg) in a Smith machine (Technogym, Spain). Swimmers were asked to place their legs in the same position that they used to perform the SS, in order to keep a control about which leg was placed front. It was requested to set the initial position with a 90º angle in front and rear knees, then leg extensions were performed. Afterwards, their lower limbs relative force values (F_{REL}) were calculated (0.95 ± 0.28), a coefficient obtained from each subject according the maximum values obtained in the previous RM test divided by their body weight. On testing day, all participants performed a SS eight minutes after a standard warm up (SWU), consisting of a varied swimming followed by dynamic lower limb stretching. This protocol was considered the control situation.

One hour later, swimmers were randomly halved in two groups in order of receiving two specific PAP methods. The first group performed the warm up with Lunge repetitions (LWU), which consisted of warming and dynamic stretching as in SWU, to which the PAP stimulus was added through the realization of the exercise Lunge in a “Smith Machine” device [3]. Swimmers were asked to place their legs in the same asymmetric position that they performed the SS. All subjects had to perform four repetitions at maximum speed to 85% of 1RM. After 8 minutes of rest, swimmers performed a SS. The second group performed the warm up with repetitions in YoYo Squat flywheel device (YWU), which consisted of warming up and dynamic stretching as in SWU, to which the PAP stimulus was added through repetitions on the “YoYo Squat” flywheel device [3]. The initial position consisted of the same position that it is performed by swimmers on the block, with the same front/behind placing of legs. Once the belt was attached, swimmers performed 4 maximum intensity repetitions. After 8 minutes of rest, the swimmers performed a SS. One hour later, that group order was reversed in order to avoid the “fatigue/learning” effect.

Kinematic Measurements

Kinematic measurements of SS were measured by recording each attempt with three digital video cameras; one of them was a high speed camera (Casio, HS Camera 300Hz) operating at a sampling rate of 300Hz; it was mounted on a tripod and focused to the block. This camera recorded the Horizontal Hip Velocity (VxH). The two other digital video cameras (Sony Video Camera, 50Hz) were fixed on the poolside; registering the Dive Distance (DD), and the time of the swim phase until 15 meters (T15m). Both block cameras were focused on the starting system to spot the light emitted by the starting signal. The starting system (Signal Frame, Sportmetrics) simultaneously emitted an audible signal and a strobe flash; this was used to synchronize the starting signal with the video image. All video files registered were analyzed by two different researchers who used the software Kinovea®, version 0.7.10., this software allowed the analysis of the reference points drawn on swimmers. The inter-observer ICC ranged from 0.98 (95% CI 0.97-0.98) to 0.99 (95% CI 0.99-0.99). These results showed a high correlation and reliability.

Statistical Analysis

Standard statistical methods were used for the calculation of means, standard deviations (SD) and *Pearson* product-moment correlation coefficients to verify the relationship between relative force and kinematic variables of a SS. Analyses were performed using SPSS software version 21.0 (IBM, Chicago, IL, USA).

RESULTS

	SWU	**LWU**	**YWU**
	Mean ± SD	**Mean ± SD**	**Mean ± SD**
Dive Distance (cm)	294.20 ± 8.67	300.29 ± 8.65	304.28 ± 9.06
Horizontal Hip Velocity (m/s)	3.63 ± 0.11	4.15 ± 0.12	4.89 ± 0.12
Time to 15m (s)	7.54 ± 0.23	7.40 ± 0.21	7.36 ± 0.22

Table 6.1. Mean and standard deviations of kinematic measurements after the three protocols (n = 14)

	SWU		LWU		YWU	
	F_{rel}(N/Kg)	P	F_{rel}(N/kg)	p	F_{rel}(N/kg)	p
Dive Distance (cm)	.933	<.001	.916	<.001	.921	<.001
Horizontal Hip Velocity (m/s)	.554	.049	.649	.016	.775	.002
Time to 15m (s)	-.901	<.001	-.906	<.001	-.887	.001

Table 6.2. Pearson's correlation coefficient between Relative Force values and SS variables (n = 14)

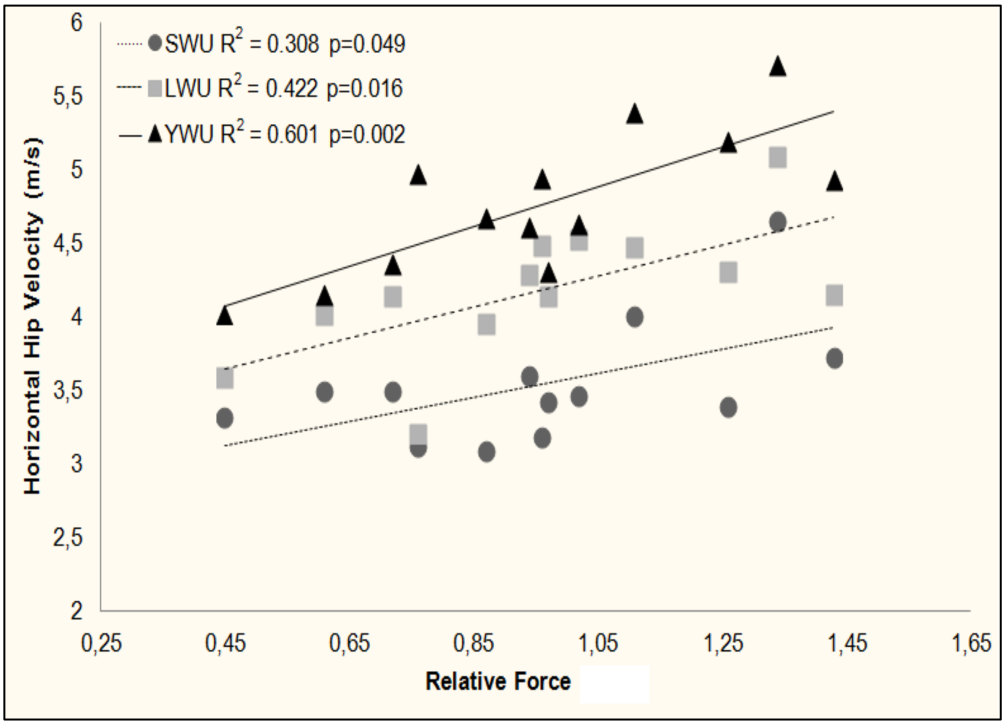

Figure 6.1. Regression analysis between Relative Force (F_{rel}) and Horizontal Hip Velocity (VxH).

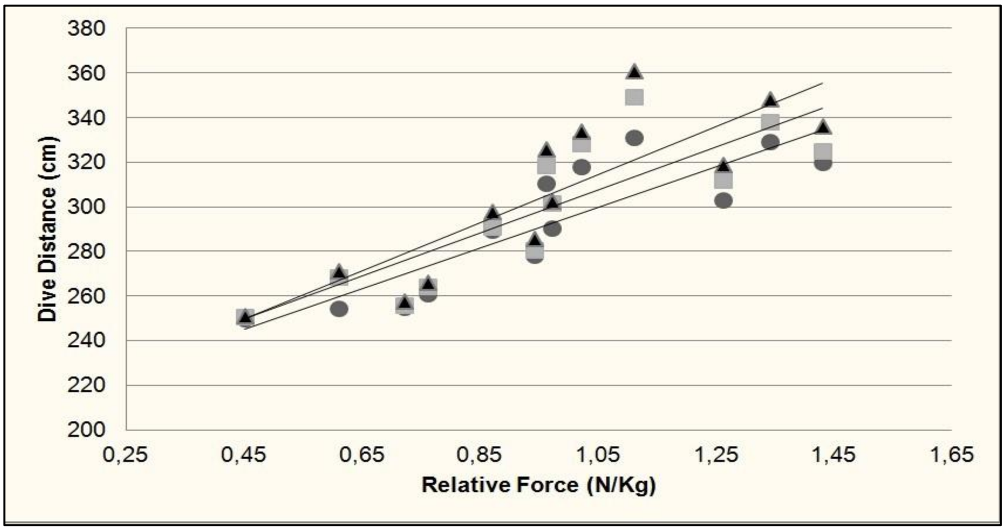

Figure 6.2. Regression analysis between Relative Force (F_{rel}) and Dive Distance.

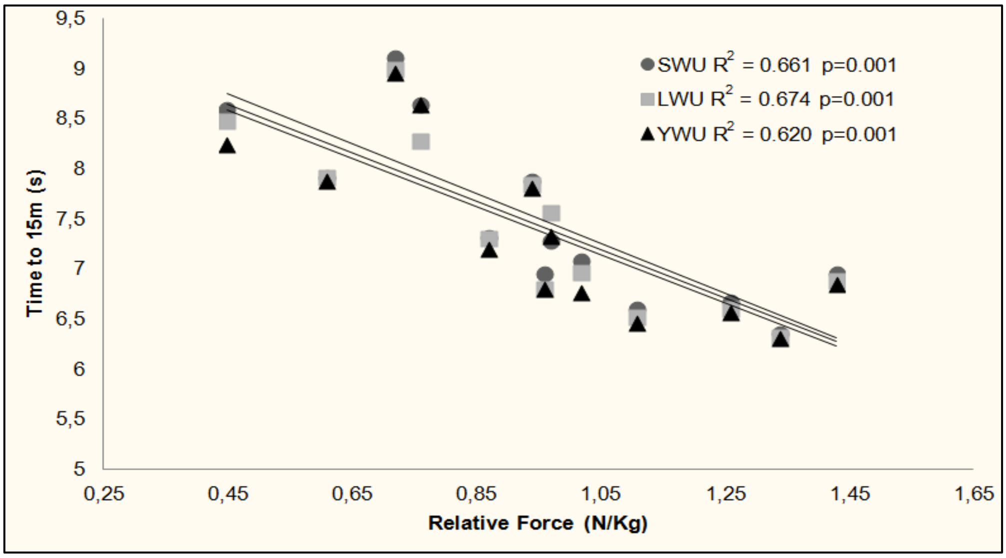

Figure 6.3. Regression analysis between Relative Force (F_{rel}) and Time to 15m.

DISCUSSION:

The analysis of the PAP effect applied in swimming start was primarily studied by Kilduff et al., (2011) [5]. In that study, PAP was proposed as an alternative to the regular warm up and they reported 8 minutes of rest as an optimal recovery time between PAP and SS. However, SS variables showed no significant improvements; maybe due to the PAP stimulus wasn't intense enough to cause potentiation. That detail was object of interest of this team and the addition of PAP to the standard warm up were evaluated in a subsequent study with the purpose of increasing such PAP stimulus [3]. In order of making comparisons possible that procedure was carried out considering the original procedure of 8 minutes of rest proposed by Kilduff et al., (2011)[5] for all the participants. By schedule restrictions, all the protocols were performed the same day.

Results showed that protocols which included specific PAP added to the regular warm up achieved better values (Table 6.1), than obtained after SWU [3]. Specifically, warm up which included the YoYo Squat repetitions (YWU) was showed as intense enough for causing the biggest improvement on performance (Table 6.1). However, no correlations of those data were made between the relative force of the subjects and the changes accounted in performance after PAP. Here is presented an updating of those results. Table 6.2 shows Pearson's correlation coefficient between baseline F_{REL} values and kinematic measurements of a SS after the changes occasioned in performance by PAP.

Kinematic variables of the SS were positive correlated with baseline F_{REL} values obtained through the Lunge exercise. T15m was negatively correlated with F_{REL}. This means, individuals with stronger lower limbs performed the swimming start in better conditions than those who showed lower values in strength tests. These results are in agreement with those showed by Beretic et al., (2013)[2] and West et al., (2011)[9]. Swimmers with higher values in F_{REL} after Lunge test achieved a higher VxH during flight ($R^2 = 0.308$, $p<0.049$), who allowed them to increase their DD ($R^2 = 0.761$, $p<0.001$) and reducing the T15m ($R^2 = -0.813$, $p=0.001$).

However, in the strength test carried out in the study of Beretic et al., (2013)[2], subjects performed isometric strength test with feet in parallel position. Meanwhile, in the study of West et al., (2011)[9], all the trials were performed by a swimming grab start. Thus, it was necessary to present an update in this field in view of an asymmetric feet placement.

When considering the changes occasioned in performance by PAP, correlations with baseline relative force values were still maintained, or they became even stronger depending on the intensity of the warm up applied, as the case of variable VxH (Table 6.2). A visual comparison to Figure 5.1, show an ascending tendency in the line regression after LWU compared with SWU, and even a higher inclination of the regression line after YWU when compared with LWU and SWU. This fact express two things; Firstly, the more F_{REL}, the higher the improvement occasioned by PAP [8]. Secondly, the more strong PAP applied [3], the higher effect in swimmers with high level of F_{REL}.

CONCLUSION:

The F_{REL} is a reliable factor for correlating the strength of the subjects with performance developed in an specific task as SS. It provides to the coach an easy tool for measuring the state of training of their subjects because it considers the body weight of the subject when mobilizing loads. Most trained individuals were able of performing a swimming start with better guarantees. To author's knowledge no one had measured this before considering the feet on an asymmetric placement. Subjects with higher values in F_{REL} showed to react better after PAP application, especially after YWU, which confirms that PAP effects are bigger the more specific is it applied and the more trained subjects are.

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CHAPTER VII

- ECCENTRIC FLYWHEEL POSTACTIVATION POTENTIATION INFLUENCES SWIMMING START PERFORMANCE KINETICS

Submitted to the Journal of Sport Sciences in March 2018

ABSTRACT:

Introduction: The aim of this study was to assess the effects of post-activation potentiation in the strength related variables of a kick start. ***Methods:*** Thirteen competitive swimmers randomly performed three kick starts in an instrumented starting block after a standardized warm up (denoted USUAL) and another after inducing post-activation through five isotonic repetitions on an eccentric flywheel (denoted PAP). A T-test was used to quantify differences in muscular performance between USUAL and PAP warm up. The best trial of each subject achieved by natural conditions (denoted PEAK) was also considered and compared with data obtained after PAP. ***Results:*** Improvements in vertical components of force were observed after PAP compared with USUAL, but no between PAP and PEAK. Horizontal peak forces were higher in PEAK condition compared with PAP ($p = 0.05$). The resultant velocity at take off was higher after PAP compared with the USUAL (4.32 ± 0.88 vs 3.93 ± 0.60 m*s-1; $p = 0.02$), however, no differences were detected compared with PAP (4.13 ± 0.62 m*s-1, $p = 0.11$). ***Conclusions:*** It suggests that slight increments in the vertical components of force, rather than in the horizontal vectors of it, might be crucial for obtaining improvements on a swimming start performance.

KEY WORDS: Warm-Up; Pre-Activation; YoYo Squat; Force Impulse

RESUMEN

Introducción: El objetivo de este estudio fue evaluar los efectos de la potenciación post-activación en las variables relacionadas con la fuerza de una salida de natación de atletismo con apoyo posterior. ***Método***: Trece nadadores de competición realizaron aleatoriamente tres salidas de natación en un bloque de salida experimental después de un calentamiento estandarizado (denominado USUAL) y otro después de inducir la post-activación a través de cinco repeticiones isotónicas en una máquina de entrenamiento excéntrico (denotado PAP). Se usó una prueba T de Student para cuantificar las diferencias en el rendimiento muscular entre el calentamiento normal y PAP. La mejor repetición de cada sujeto lograda en condiciones naturales (denominada PEAK) también se consideró y se comparó con los datos obtenidos después de PAP. ***Resultados:*** Se observaron mejoras en los componentes verticales de la fuerza después de PAP en comparación con USUAL, pero no entre PAP y PEAK. Las fuerzas máximas horizontales fueron más altas en la condición PEAK en comparación con PAP ($p = 0.05$). La velocidad resultante en el despegue fue mayor después de PAP en comparación con el USUAL (4.32 ± 0.88 vs 3.93 ± 0.60 m * s-1; $p = 0.02$), sin embargo, no se detectaron diferencias en comparación con PAP (4.13 ± 0.62 m * s- 1, $p = 0{,}11$). ***Conclusiones:*** Estos resultados sugieren que pequeños incrementos en los componentes verticales de la fuerza, en lugar de en los vectores horizontales de la misma, podrían ser cruciales para obtener mejoras en el rendimiento de una salida de natación.

INTRODUCTION

The swim start is a combination of explosive movements intended to impel the swimmer from the starting block into the water using an optimal steering strategy [23]. It should include a fast reaction time, significant jump power, high take-off velocity and low hydrodynamic drag during entry [4, 18]. In sprint events, a fast start is fundamental for competitive swimming success [2, 30], contributing 0.8 to 26.1% to the final result [6]. Since the introduction of the Omega starting block (OSB11, Corgémont, Switzerland) in 2011, the so-called kick start has been used by almost all competitive swimmers as they can obtain advantage in terms of block time and body stability due to an increase in horizontal velocity and balance resulting by the reaction forces produced against the rear plate [18, 25, 30]. Adopting a rear weighted body position rather than try to get off as quick as possible appears to be the preferred approach taken by elite swimmers to achieve a high impulse at take-off [2, 3]. On that case, lower limbs activation should be maximized [4, 8].

The selected load eliciting PAP is frequently obtained some days prior to the test [7, 9, 29]. However, at the day of the test subjects may have varied their final performance, either due to skills deterioration/improvement or, even, if the load was not properly obtained. Previous results reported by Cuenca-Fernandez, Lopez-Contreras and Arellano, (2015) [7] showed that it would be interesting to use inertial systems to solve this issue. Improvements in kinematical variables of a swim start were obtained as a consequence of adding repetitions on an eccentric flywheel right after the swimming warm up. Authors concluded that as the resistance was proportional to the force applied, it generated high lower limb activation due to the high requirements of power and strength in the concentric and eccentric phases from the first repetition of each set [10]. Hence, maximal muscle stimulation can be achieved regardless of a subject’s condition on the day of the test, with possible great benefits on subsequent kick start performance.

Although applying this specific pre-activation protocol in competition seems unfeasible (a specialist piece of equipment is required while athletes are waiting in the call-up room), the influence of PAP on swimming start kinematical variables have showed optimistic outcomes, at least in experimental conditions [7]. Therefore, the effects of the propelling forces acting on the block should be better understood. In fact, by using a swimming instrumented `kick start block´ with independent triaxial force plates [11, 23], it will be possible to obtain the strength variables related with the impulse and explosiveness of each limb at take-off, but also identifying the performance variations magnitude associated to the application of PAP. The aim of the current study was to verify if swimming kick start performance can be improved by using a conditioning exercise based on flywheel eccentric submaximal repetitions.

METHODS:

Approach to the problem:

A T-test design was used to compare swimmers muscular performance in an instrumented starting block (Figure 7.1) [11, 23]. Two conditions were randomly tested; the first condition (denoted USUAL), was obtained by averaging three kick starts performed after a standard warm up. The second condition (denoted PAP), consisted on the same warm up performed in the USUAL condition and followed by PAP inducement through five repetitions on an eccentric flywheel. The PAP conditioning exercise focused on lower limbs muscles was performed on an inertial flywheel nHANCE™ Squat Ultimate (YoYo™ Technology AB, Stockholm, Sweden), allowing the realization of a motion very similar to the real starting action (Figure 7.2). The trial expressing the highest value of resultant velocity of each swimmer was identified from the three kick starts performed in the USUAL condition. This `best trial´ (denoted PEAK), gathered the best outcomes obtained for each subject across standard trials (regardless the trial in which were performed), and was compared with the PAP condition with the purpose of detecting if a start using PAP might be faster than the fastest start that a swimmer could do without PAP.

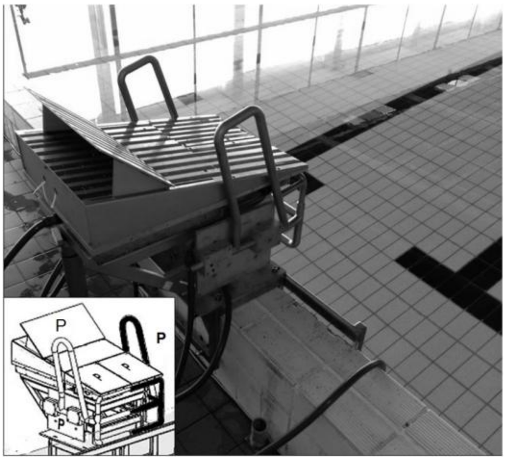


Figure 7.1. Instrumented swimming starting block, replicating OMEGA OSB 12, with its five independent extensiometric triaxial force plates (P).

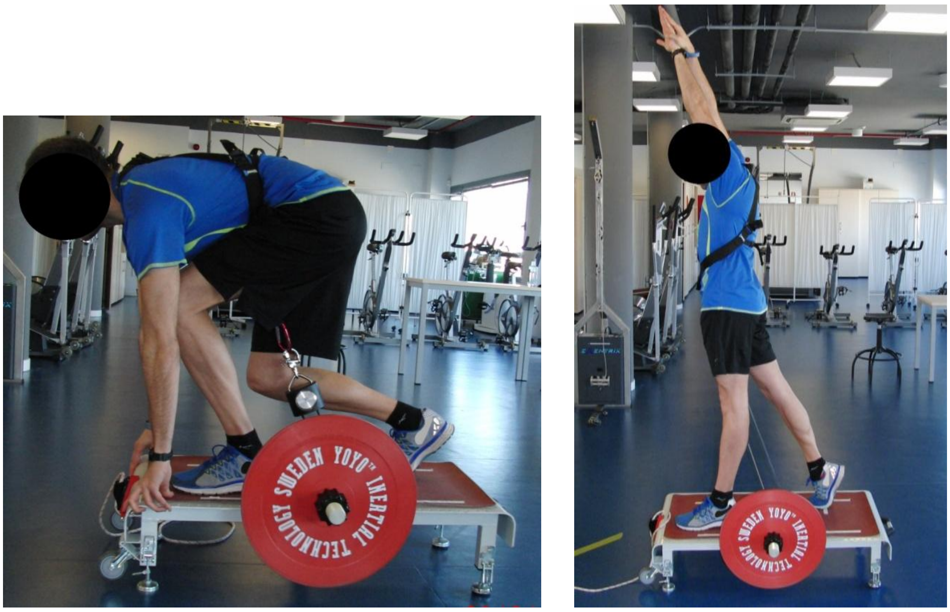


Figure 7.2. Initial and final positions of the conditioning exercise on the nHANCE™ Squat Ultimate simulating a swimming kick start (left and right panels, respectively).

Subjects:

Thirteen competitive swimmers volunteered to take part in this study. The male (n=11) and female (n=2) main physical and competitive background characteristics are (mean ± SD): 18.95 ± 1.63 vs 19.02 ± 0.78 years old, 76.61 ± 9.12 vs 59.43 ± 8.23 kg of body mass, 1.81 ± 0.03 vs 1.62 ± 0.05 m of height and ≤ five years of national level competitive participation. Swimmers received information about the experimental procedures and possible risks associated, were asked to provide informed consent before the testing started and refrained from alcohol, caffeine and strenuous exercise for the previous 24 h.

Variables Measured:

The variables measured in the current study are described in Table 7.1.

NAME	DESCRIPTION	FORMULA
Reaction Time	Time between the starting signal (trigger) and time in which ground reaction forces (GRF) change from body mass (m_b).	$RT = t_{(GRF \neq m_b)} - t_{(Trigger)}$
Movement Time	Time between the reaction time and the end of the push-off (GRF dropped to 0).	$MT = t_{(GRF=0)} - t_{(GRF \neq m_b)}$
Block Time	The sum of reaction time and movement time.	$BT = RT + MT$
Average Force	Calculated as horizontal/vertical impulse divided by movement phase time.	$AvF = \frac{Impulse}{MT}$
Peak Force	The greatest horizontal/vertical force reached during the movement phase.	$PeF = Max\ (\Delta F)$
Horizontal Force Impulse	Where s stands for the instant of the force change, e for the end of push-off and Fh stands for horizontal forces; Δt was 1/2000 (frequency of data acquisition: 2000 Hz).	$I_H = \sum_{s}^{e} F_h\, \Delta t$
Vertical Force Impulse	Where m_b stands for the body mass; Fv for the sum of the vertical forces exerted by the rear and the front leg (forces while waiting for the start signal were extracted).	$I_V = \sum_{s}^{e} (F_v - m_b g)\Delta t$
Resultant Impulse	Calculated from component's impulses (horizontal & vertical) using Pythagorean Theorem.	$I_{Res} = \sqrt{{I_H}^2 + {I_V}^2}$
Velocity *Horizontal/Vertical*	Calculated from corresponding force impulse (Horizontal or vertical) at take-off, divided by body mass (m_b).	$Vel = \frac{I}{m_b}$
Resultant Velocity	Calculated as resultant impulse at take-off divided by body mass (m_b).	$Res_v = \frac{I_R}{m_b}$
Average Acceleration	Calculated as average horizontal/vertical force divided by body mass (m_b).	$AvAccel = AvF\ /\ m_b$
Peak Acceleration	Calculated as peak horizontal/vertical force divided by body mass (m_b).	$PeAccel = PeF\ /\ m_b$
Power *(Average/Peak)*	Calculated as (average or peak) horizontal/vertical force multiplied by horizontal/vertical velocity.	$Av_{Power} = AvF \cdot Velocity$ $Pe_{Power} = PeF \cdot Velocity$
Resultant Power	Calculated from component's Average/Peak power using Pythagorean Theorem.	$Res_{Power} = \sqrt{{Pw_H}^2 + {Pw_V}^2}$
Rate of Force Development	Obtaining the horizontal/vertical component of Rate of Force Development as peak horizontal/vertical force divided by time to reach it; and applying the Pythagorean Theorem.	$RFD = \sqrt{{RFD_h}^2 + {RFD_v}^2}$
Force Rear/Front Leg	Calculated as horizontal/vertical impulse of the rear or front leg acquired with the rear/front force plate, divided by movement phase time of the rear/front leg.	$Force = \frac{I_{Rear/Front}}{MT}$
Horizontal Impulse *(Rear/Front Leg)*	Where s stands for the instant of the force change, e for the end of push-off and Fh represented the horizontal forces exerted by the rear/front leg; Δt was 1/2000 (Hz).	$I_{Hor} = \sum_{s}^{e} F_h \cdot \Delta t$
Vertical Impulse *(Rear/Front Leg)*	Where Fv stands for the vertical force registered in the rear/front plate; m_b stands for the body mass registered in the rear/front leg and Δt for 1/2000 (Hz).	$I_{Ver} = \sum_{s}^{e} (F_v - m_b g)\ \Delta t$

Table 7.1. Description and formula of the variables measured in the instrumented swimming start block.

PROCEDURES:

All procedures were performed in accordance with the requirements of the Declaration of Helsinki and were approved by the local ethics committee. In a 25-m indoor pool (28.2 and 29.1ºC of water and air temperatures), participants were randomly assigned into two conditions. The first condition replicated the swimming warm up previously applied by Cuenca-Fernandez et al., (2015) [7] for the same experimental testing. It consisted of a conventional warm up of 400 m at front crawl moderate intensity and two starts from the wall. Then, they performed a dynamic stretching protocol, consisting on specific exercises for jump performance, with each performed 10 times with the entire set repeated twice (one set per min). After six min of rest, swimmers performed three kick starts (with 6 min intervals in-between) on a dynamometric instrumented starting block (complying with FINA rules; FR 2.7) that included five triaxial and independent above water force plates, two for hands and two for feet force measurements [11]. Data acquisition, used filters and general procedures of data management were fully described before [11, 23]. An auditory stimulus, as in competition, was used as a starting signal and was synchronized with force plates

In the second condition, warm up followed by repetitions in eccentric flywheel were replicated according to Cuenca-Fernandez et al., (2015) [7]. Briefly, characteristics of the device used are fully described on references[32]. The initial position consisted on the same position that was performed by swimmers on the starting block, with the same front/behind placing of lower limbs (Figure 7.2). Once the belt was attached, each swimmer performed five maximum intensity repetitions. The reason for the election of five repetitions was that the first repetition serves to charge the flywheel spin. During the entire exercise, a study collaborator monitored the initial position and provided swimmers with the device harnesses. Subsequently, each swimmer performed a swim start after six min of rest. On the study of Cuenca-Fernandez et al., (2015)[7], eight minutes of rest were given between PAP conditioning exercise and test. On the present study though, only six minutes of rest were given between PAP and swim start testing, as some literature showed as acceptable for dissipating fatigue while activation still exists [17, 21].

Statistical analysis:

Descriptive statistics were obtained and data were expressed as mean ± SD and respective effect sizes (SPSS Version 21.0, IBM, Chicago, IL, USA). After Saphiro-Wilk testing for normality distribution, T-test ANOVA was carried out to determine differences concerning the USUAL (average across trials 1-3) to the PAP condition. To detect differences between variables, significance was accepted at the alpha < 0.05 level. The same analysis was applied to compare results from PAP protocol with results from the PEAK condition. The criterion for selecting that particular trial and all the variables associated to such specific achievement was the highest value expressed for resultant velocity.

RESULTS:

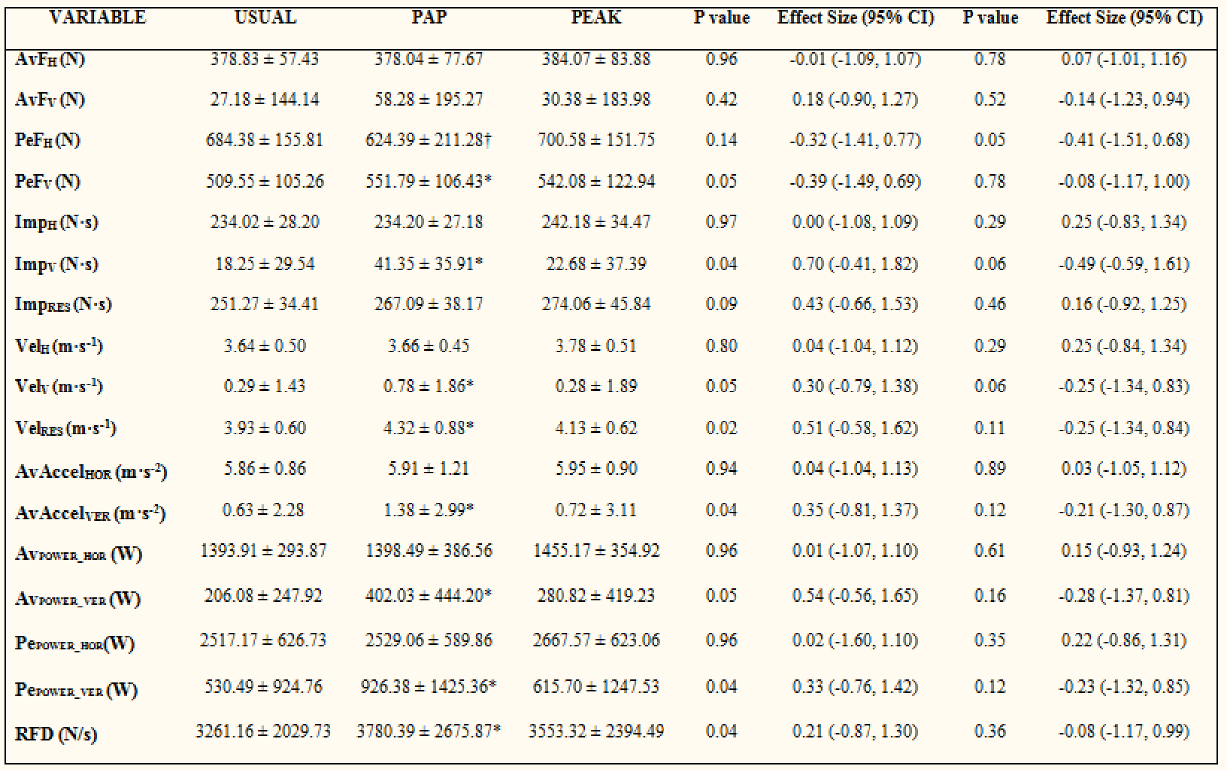
Mean, SD, *p* – values and effect sizes for all tested swimming starts related variables are presented in Table 7.2 for the three conditions. The values variations achieved along the tests depending on the swim start or condition are shown for each trial in Figure 7.3. No differences were found for reaction time, movement time or block time in any of the comparisons between USUAL and PAP ($p > 0.1$), nor when the PEAK condition was consider on the analysis.

The average horizontal and vertical force registered on the block did not vary on any of the conditions exerted and no variations were observed when compared after PAP condition with the PEAK (Table 7.2). Peak horizontal force values not showed differences between the USUAL and PAP condition. Nonetheless, values after PAP condition were lower than in the PEAK (PAP trial: 624.39 ± 58.60 N vs. PEAK trial: 700.58 ± 30.99 N) (Figure 7.3, Plot A). Peak vertical force values were higher after PAP condition than obtained after the USUAL, but no differences were found when performance after PAP condition was compared with the PEAK (Table 7.2). Subjects did not vary horizontal impulse exerted on the plates. When analyzing vertical impulse values, differences were showed comparing the USUAL and the PAP trial ($p = 0.04$) (Table 7.2). A trend close to show significance was detected comparing PAP and the PEAK ($p = 0.059$), as subjects achieved the highest values of the test after experimental condition (Figure 7.3, Plot B). Resultant impulse values did not show differences between any of the three conditions.

The values of horizontal velocity kept stable along the experiments (Figure 7.4, Plot A). Differences in vertical velocity were observed between the USUAL and PAP trial ($p = 0.05$). Analysis was close to reveal differences comparing vertical velocity in the PAP trial with the PEAK ($p = 0.058$). Resultant velocity values were higher for the PAP trial in comparison to the USUAL ($p = 0.028$), but no comparing with the PEAK (Table 7.2).

Values obtained in horizontal acceleration and power (average and peak) did not show differences in any condition. Conversely, differences were found between USUAL and PAP in vertical acceleration (average) and vertical power (average) (Table 7.2). Results for vertical acceleration and power (peak) at PAP trial achieved the highest value of the test, but differences only were found compared with the USUAL (Table 7.2). Values for resultant power (average and peak) did not show statistical differences in any of three conditions (Figure 6.4, Plots B & C).

The rate of force development expressed differences between USUAL and PAP trial (p = 0.04). Values after PAP were the highest registered in the test. However, no differences were found when comparing with the values from the PEAK (Table 7.2). No differences were found for horizontal force/impulse and vertical force/impulse from the rear leg in any of the comparisons made between USUAL and PAP trial, and also comparing the PAP trial with the PEAK (p > 0.1). Analyzing horizontal force/impulse and vertical force/impulse from the front leg, no differences were revealed between USUAL and PAP trial (p > 0.1), nor comparing with the PEAK (Figure 7.3, Plots C & D).



VARIABLE	USUAL	PAP	PEAK	P value	Effect Size (95% CI)	P value	Effect Size (95% CI)
AvF$_H$ (N)	378.83 ± 57.43	378.04 ± 77.67	384.07 ± 83.88	0.96	-0.01 (-1.09, 1.07)	0.78	0.07 (-1.01, 1.16)
AvF$_V$ (N)	27.18 ± 144.14	58.28 ± 195.27	30.38 ± 183.98	0.42	0.18 (-0.90, 1.27)	0.52	-0.14 (-1.23, 0.94)
PeF$_H$ (N)	684.38 ± 155.81	624.39 ± 211.28†	700.58 ± 151.75	0.14	-0.32 (-1.41, 0.77)	0.05	-0.41 (-1.51, 0.68)
PeF$_V$ (N)	509.55 ± 105.26	551.79 ± 106.43*	542.08 ± 122.94	0.05	-0.39 (-1.49, 0.69)	0.78	-0.08 (-1.17, 1.00)
Imp$_H$ (N·s)	234.02 ± 28.20	234.20 ± 27.18	242.18 ± 34.47	0.97	0.00 (-1.08, 1.09)	0.29	0.25 (-0.83, 1.34)
Imp$_V$ (N·s)	18.25 ± 29.54	41.35 ± 35.91*	22.68 ± 37.39	0.04	0.70 (-0.41, 1.82)	0.06	-0.49 (-0.59, 1.61)
Imp$_{RES}$ (N·s)	251.27 ± 34.41	267.09 ± 38.17	274.06 ± 45.84	0.09	0.43 (-0.66, 1.53)	0.46	0.16 (-0.92, 1.25)
Vel$_H$ ($m \cdot s^{-1}$)	3.64 ± 0.50	3.66 ± 0.45	3.78 ± 0.51	0.80	0.04 (-1.04, 1.12)	0.29	0.25 (-0.84, 1.34)
Vel$_V$ ($m \cdot s^{-1}$)	0.29 ± 1.43	0.78 ± 1.86*	0.28 ± 1.89	0.05	0.30 (-0.79, 1.38)	0.06	-0.25 (-1.34, 0.83)
Vel$_{RES}$ ($m \cdot s^{-1}$)	3.93 ± 0.60	4.32 ± 0.88*	4.13 ± 0.62	0.02	0.51 (-0.58, 1.62)	0.11	-0.25 (-1.34, 0.84)
AvAccel$_{HOR}$ ($m \cdot s^{-2}$)	5.86 ± 0.86	5.91 ± 1.21	5.95 ± 0.90	0.94	0.04 (-1.04, 1.13)	0.89	0.03 (-1.05, 1.12)
AvAccel$_{VER}$ ($m \cdot s^{-2}$)	0.63 ± 2.28	1.38 ± 2.99*	0.72 ± 3.11	0.04	0.35 (-0.81, 1.37)	0.12	-0.21 (-1.30, 0.87)
Av$_{POWER\_HOR}$ (W)	1393.91 ± 293.87	1398.49 ± 386.56	1455.17 ± 354.92	0.96	0.01 (-1.07, 1.10)	0.61	0.15 (-0.93, 1.24)
Av$_{POWER\_VER}$ (W)	206.08 ± 247.92	402.03 ± 444.20*	280.82 ± 419.23	0.05	0.54 (-0.56, 1.65)	0.16	-0.28 (-1.37, 0.81)
Pe$_{POWER\_HOR}$ (W)	2517.17 ± 626.73	2529.06 ± 589.86	2667.57 ± 623.06	0.96	0.02 (-1.60, 1.10)	0.35	0.22 (-0.86, 1.31)
Pe$_{POWER\_VER}$ (W)	530.49 ± 924.76	926.38 ± 1425.36*	615.70 ± 1247.53	0.04	0.33 (-0.76, 1.42)	0.12	-0.23 (-1.32, 0.85)
RFD (N/s)	3261.16 ± 2029.73	3780.39 ± 2675.87*	3553.32 ± 2394.49	0.04	0.21 (-0.87, 1.30)	0.36	-0.08 (-1.17, 0.99)

Table 7.2. Mean, SD, p – value and effect sizes for the strength variables obtained from the experimental swimming start block in the three studied conditions (n=13).

* Differences ($p < 0.05$) in performance compared with USUAL.
† Differences ($p < 0.05$) in performance compared with PEAK.

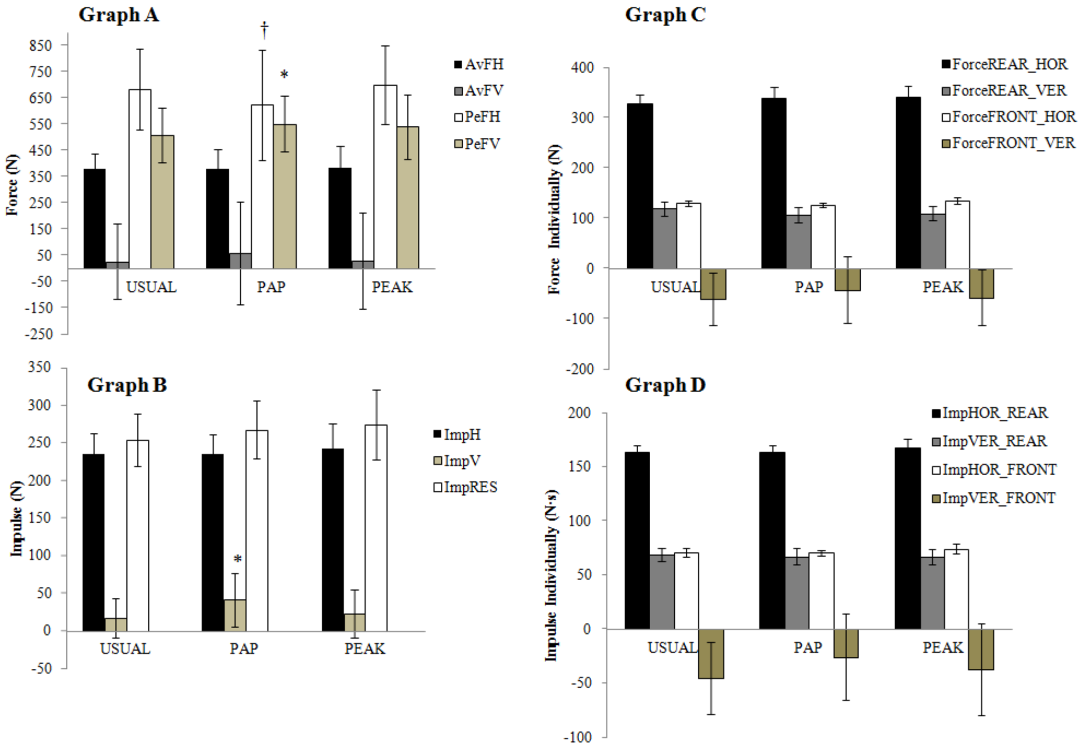


Figure 7.3. Variation of ground reaction forces variables depending on the swimming start and/or the condition performed. (AvFH, AvFV, PeFH and PeFV: Horizontal/vertical force average or peak; ForceREAR_HOR, ForceREAR_VER, ForceFRONT_HOR and ForceFRONT_VER: Horizontal/vertical force rear or front leg; ImpHOR_REAR, ImpVER_REAR, ImpHOR_FRONT and ImpVER_FRONT: Horizontal/vertical impulse rear or front leg; (USUAL: Swimming start average values across trials 1-3; PAP: swimming start after post-activation performance enhancement; PEAK: The best trial of each subject achieved by natural conditions on the standard trials) (N=13).

* Differences ($p < 0.05$) in performance compared with USUAL.
† Differences ($p < 0.05$) in performance compared with PEAK.

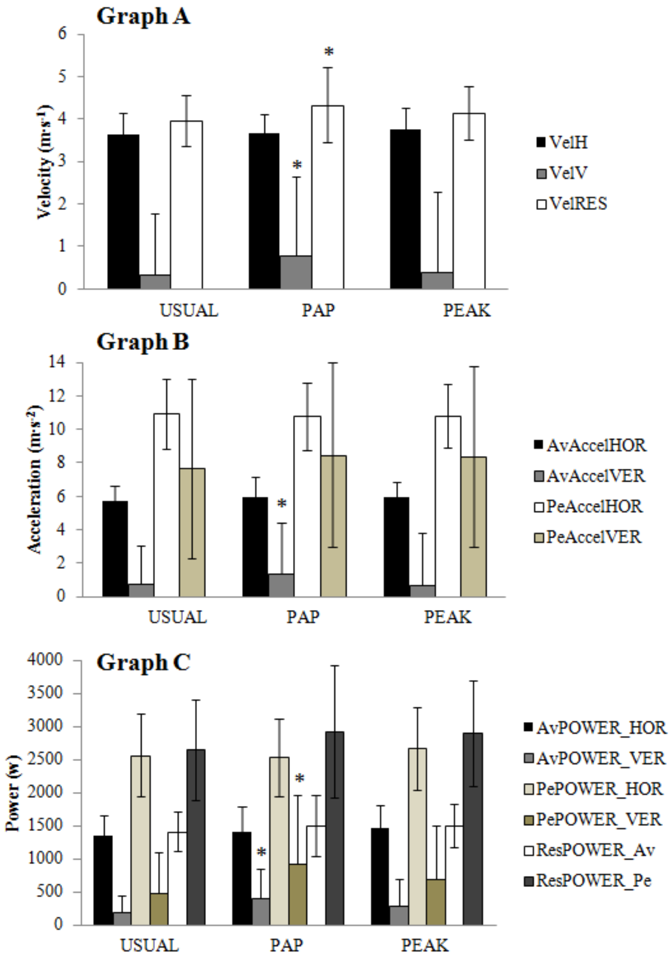


Figure 7.4. Variation of velocity, acceleration and power variables depending on the swimming start and/or the condition performed (VelH, VelV and VelRES: horizontal, vertical and resultant velocities; AvAccelHOR, AvAccelVER, PeAccelHOR and PeAccelVER: horizontal/vertical and average or peak acceleration. AvPOWER_HOR, AvPOWER_VER, PePOWE_HOR, PePOWER_VER, ResPOWER_Av and ResPOWER_Pe: horizontal/vertical, average or peak and resultant power; (USUAL: Swimming start average values across trials 1-3; PAP: swimming start after post-activation performance enhancement; PEAK: The best trial of each subject achieved by natural conditions on the standard trials) (N=13).

* Differences ($p < 0.05$) in performance compared with USUAL.
† Differences ($p < 0.05$) in performance compared with PEAK.

DISCUSSION:

The purpose of this study was to observe if the kick start performance could be improved after a PAP protocol. Our results suggest that swimming start performance can be slightly improved after five submaximal repetitions conducted on an eccentric flywheel, as a result of enhancements in the vertical components of the swimming start action. However, given the small size of the differences comparing the results obtained after PAP protocol with those collected from the best trial (PEAK) and the lack of effects in all the variables related with the horizontal component of force production, no evidence of superiority in the PAP method can be assumed than achieved by natural conditions.

Swim starts are explosive and organised movements intended to propel the swimmer from the starting block as quick and as far as possible [23]. According to some authors [13, 25], by using the kick start, is preferable to give up some reaction time to earn in movement time and consequently in impulse [2]. In the current study, no variations regarding temporal variables were detected in any of the conditions. This was a positive point as, although no comparison between different start techniques was made, swimmers showed high consistency between trials even when some small variations occurred in performance. In short events, hundredths of seconds are key points of success and swimmers need to train the ability of reacting fast after the starting signal. Therefore, little or no benefit might be obtained after an improved take-off velocity if the time spent on the block is too large [28].

According to some authors, the block phase influences the performance in subsequent components of the start and, therefore, it is important for swimmers to optimize it [22]. Some studies have shown the relationship between lower body muscle force and start performance [4, 8, 14, 30, 34] and the results suggests that swimmers who possess greater maximum force and specific rate of force development at absolute and relative levels, tend to achieve faster velocities at take-off and to swim faster on initial meters of a swim start performance [4, 34]. Swimmers experienced a change on performance by generating more vertical force and velocity and such effects contributed to transfer this improvement to the total resultant movement. As a result, resultant velocity took part of such vector distribution and subjects obtained an improvement on their performance for leaving the block at a higher resultant speed (Figure 7.4, Graph A). Unfortunately, kinematic variables were not added to our results, thereupon we could not certify that swimmers entered into the water with a longer diving distance, entry angle or time to reach the 5 meters as a consequence of such improved speed.

In the present study, no improvements were observed after PAP for any of the horizontal variables derived from the force plates: ground reaction forces, acceleration and impulse (average and peak). Meanwhile vertical forces improved as a result of the PAP stimulation and it was transferred to all the dependant variables of vertical force (average & peak). Considering that improvements in performance seen after PAP are very specific to the task used as a condition of warm-up [29], it is conceivable to argue that the lack of improvement in the horizontal direction might be a consequence of a PAP conditioning exercise with a predominance of vertical movement (Figure 7.2). This results are in conflict with obtained by Kilduff, Cunningham, Owen, West, Bracken and Cook, (2011) [19]. Traditional swimming warm up was substituted by an experimental protocol based on three maximal back squat repetitions at 87% of 1RM [19]. Swimmers were then tested in a swimming start by using a force plate placed on the swimming block and the outcomes revealed that both peak horizontal and vertical forces exerted on the block were indeed augmented after such experimental warm up. In spite of both studies purported mimicking the kinesiological-lower limbs movement of a swimming start through vertical-based movements, the results obtained on the present study seemed to show some constraints directly emanated from the conditioning exercise, possibly due to the asymmetric feet emplacement while executing the exercise [10].

Nonetheless, the results of Kilduff et al., (2011) [19] were obtained in a `track ventral start´ by using a single force plate mounted on the block. Meanwhile in the current study, a `kick start´ was tested on an experimental block start composed by multiple force plates (Figure 7.1). Fact contributing to a different interpretation of the results [11]. Swimming starts performed in the OMEGA starting block allow swimmer to obtain an advantage in terms of stability and force production [18, 25, 30]. When horizontal force and horizontal movement is guaranteed by the movement done by the rear foot on the rear plate, the front lower extremity may assume a higher implication to provide a vertical impulse on the system; Although alterations on the present study were only trends, this fact was suggested by the vertical force and impulse values obtained on the front leg in this study, moreover because they are in agreement with the ones obtained in a previous research [31]. Taking into account the characteristics of the conditioning exercise, more force is produced by the front leg given the asymmetric feet placement on the flywheel device and the eccentric overload while breaking the flywheel [10, 24]. The subsequent impulse action of each repetition, could have supposed thus favourable adaptations to the first stages of a swimming start impulse, where an overload on the front leg provided by the pull action of hands compressing the body against the block [31] is solved with a subsequent force production.

Regarding the variables related to the explosiveness of the take-off, no large differences were found. The results are nonetheless worthy of review, particularly in light of the fact that resultant power values were slightly higher after PAP in comparison to any condition (Table 7.2; Figure 7.4, Graph C). One reason behind the small differences detected, might be the relationship between force exerted on the block and the speed of the movement [27]. According to some authors [1, 5, 12] the speed of the movements could have an important role on the fast muscle fibber units activation, thus high intensity stimulus (100%) performed at slower speed could have an attenuation effect of the neural output, reducing the possibility of favourable adaptations in subsequent power exercises**.** Power is the product of force and speed, and in spite of repetitions on eccentric flywheel definitively caused a transitory improvement in force applied on the block, the lack of plyometric characteristics may have had null influence on increasing the speed of movements and, therefore, in power [24, 33].

As rate of force development is an expression of force production in short time, the improvement of the values obtained in this variable could support the idea that explosiveness could be sensible to be improved after PAP protocols previously proposed by some authors [4, 34]. Results showed on this study partially supported such idea, as differences were only found by comparing PAP values with those obtained after the USUAL condition, but no differences were found when values of rate of force development after PAP were compared with the PEAK. Possibly, the effects of actin-myosin phosphorilation increases peak forces after PAP, producing the improvements found in force components on that condition [15, 20]. However, a possible limitation of this study may reside on the fact that effects of PAP have been also reported on the neuromuscular system due to an intensification of the muscle fiber recruitment when muscle contractions are performed at high speed [16, 26]. Considering that in the USUAL condition three kick starts were performed in a row, the possible effects of the motor-neuron's excitation elicited by the maximal voluntary take-off extension movement, might be the reason behind optimal performance was also achieved by natural conditions.

In conclusion, by applying a conditioning exercise based on repetitions on eccentric flywheel, some improvements in performance (associated to PAP effect) can be indeed obtained, as it caused a moderated influence on swimming start performance. This improvement would come due to the improvement obtained in the vertical axes of force production. It suggests that slight increments in the vertical components of force/impulse, rather than in the horizontal vectors of it, might be crucial for obtaining improvements on a swimming start performance. The relevance of our study is the application of a system to improve performance of swimmers on a swim ventral start. The effect on velocity at take-off or the increase in vertical forces exerted on the block leads us to consider the use of this device prior to competition in short events. However, given the unfeasibility of using it six minutes prior to getting on the block or while waiting in the call-up room, lead us to recommend it preferably as an interesting training tool for coaches, as an extension movement can be effectively performed with lower limbs. Therefore, the possible modifications induced on technique as well as the adaptations of this kind of methods to competitive constraints should be resolved in the future.

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CHAPTER VIII

- EFFECTS OF TWO TYPES OF ACTIVATION PROTOCOLS BASED ON PAP ON 50-METER FREESTYLE PERFORMANCE

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ABSTRACT

Introduction: Postactivation potentiation (PAP) is a phenomenon which improves muscle contractility, strength and speed in sporting performances through previously applying maximal or submaximal loads on the muscle system. This study aimed to assess the effects of two types of activation protocols based on PAP, on sprint swimming performance. ***Methods:*** A repeated-measures design was used to compare three different scenarios prior to a 50-m race. First, all of the participants performed a standard warm-up (SWU), consisting of 400-m swimming followed by dynamic stretching. This protocol acted as the control. Subsequently, the swimmers were randomly assigned into two groups: the swimmers in the first group performed the SWU followed by PAP inducement through one set of three "lunge" and three "arm stroke" repetitions, both at 85% of the one-repetition maximum (denoted RMWU). The swimmers in the second group performed the SWU followed by PAP inducement through one set of four repetitions of exercises of both the lower and upper limbs on an adapted eccentric flywheel at the maximal voluntary contraction (denoted EWU). ***Results:*** The time required for the swimmers to swim 5 and 10 m was shorter with the PAP protocols. The swimming velocity of the swimmers who underwent the EWU and RMWU protocols were faster at 5 and 10 m. The best total swimming time was not influenced by any of the protocols. When isolating swimming phase (excluding start performance and turn), best time was achieved with the SWU and RMWU compared with EWU (SWU: 20.86 ± 0.95 s; EWU: 21.25 ± 1.12 s; RMWU: 20.97 ± 1.22 s). ***Conclusions:*** In conclusion, a warm up based on PAP protocols might exert an influence on performance in the first meters of a 50-m race. Nevertheless, other factors, such as fatigue, could modify swimming patterns and yield results contradictory to those of the desired task.

KEYWORDS: Flywheel, Warm-up, PAP, OSB11 Block, Sprint Swimming.

RESUMEN

Introducción: La potenciación post-activación (PAP) es un fenómeno que mejora la contractilidad muscular, la fuerza y la velocidad en los gestos deportivos a través de la aplicación previa de cargas máximas o submáximas en el sistema muscular. Este estudio tuvo como objetivo evaluar los efectos de dos tipos de protocolos de activación basados en PAP, en el rendimiento en una prueba de natación de velocidad (50-m). ***Métodos:*** se utilizó un diseño de medidas repetidas para comparar tres protocolos diferentes antes de una carrera de 50 m. En primer lugar, todos los participantes realizaron un calentamiento estándar (SWU), que consistió 400 m de nado variado seguido de un protocol de estiramiento dinámico. Este protocolo actuó como situación de control. Posteriormente, los nadadores fueron asignados aleatoriamente en dos grupos: los nadadores en el primer grupo realizaron el SWU seguido de inducción de PAP a través de un protocolo de tres repeticiones de "zancada" y tres de "brazada", ambas al 85% de una repetición máxima (denotado RMWU). Los nadadores en el segundo grupo realizaron el SWU seguido de la inducción de PAP a través de un protocol de cuatro repeticiones de ejercicios de los miembros inferiores y superiores en una máquina de entrenamiento excéntrico adaptada (EWU). ***Resultados:*** El tiempo requerido para que los nadadores nadasen 5 y 10 m fue más corto con los protocolos PAP. La velocidad de nado de los nadadores que se sometieron a los protocolos EWU y RMWU fue más rápida en 5 y 10 m. El tiempo total de natación no fue influenciado por ninguno de los protocolos. Al aislar la fase de natación (excluyendo el rendimiento de inicio y el giro), el mejor tiempo se logró con el SWU y RMWU en comparación con EWU (SWU: 20.86 ± 0.95 s; EWU: 21.25 ± 1.12 s; RMWU: 20.97 ± 1.22 s). ***Conclusiones:*** En conclusión, un calentamiento basado en los protocolos PAP podría influir en el rendimiento en los primeros metros de una carrera de 50 m. Sin embargo, otros factores, como la fatiga, podrían modificar los patrones de natación y arrojar resultados contradictorios a los de la tarea deseada.

INTRODUCTION

In sprint swimming events every instant is critical [15]. In the last Olympics in Rio 2016, only one hundredth of a second (0.01 s) determined the difference between the first (A.E., USA: 21.40 s) and the second qualified (F. M., FRA: 21.41 s) swimmer on the 50-m male freestyle (www.fina.org). At this level of performance, small variations in speed resulting from the start performance, underwater swimming or stroke patterns are definitively essentials points to success [16]. One key aspect in the preparation of the swimmers might involve the physical warm-up and all possible activities that are particularly designed to produce an optimal cortical activation for the desired task [12]. A combination of dry land-based activation exercises followed by pool-based warm-up routines appears to be the preferred approach taken by elite swimming coaches preparing their athletes for competition [9]. Some of these methods are based on postactivation potentiation (PAP), a phenomenon which improves muscle contractility, strength and speed in sporting performances by having previously applied maximal or submaximal loads on the muscle system [14, 17].

Two studies that aimed to determine the relationships among resistance exercise and swim performance inspired the warm-up protocols applied on the present study [2, 10]. In both studies, arm stroke exercises replicating the front crawl underwater phase were tested through adapted devices. The subjects laid in prone position on a 45º inclined bench, extended their arms horizontally to the front, and pulled two handles connected to ropes, which were fully extended and tensed into the device, replicating the biomechanical gestures of swimming. The results of the first study [2], showed that maximum power on the arm stroke exercise was relatively similar to maximum swim power (r = 0.91), and both of these powers were related to swim velocity (r = 0.85, r = 0.72). The second study (10) showed improvements in 100- (-1.83%) and 50-m (- 0.76%) performance, and these gains were related to increases in muscle strength (12.8%) and muscle power (14.2%) gained through four weeks of inertial training of the muscles involved in the upsweep phase of the arm stroke in front crawl swimming. Authors concluded that greater increases in muscle power could result from greater muscle stimulation during eccentric vs traditional weight training and claimed for additional research testing this kind of protocols on swimming performance.

Hence, if the performance of a dry land test is related to swimming velocity and power, which can be elicited through isotonic load lifting exercises (free-weight and eccentric-resistance exercises), a competition warm-up that includes some of the above-mentioned methods could yield interesting improvements. Previous results reported by Cuenca-Fernandez, Lopez-Contreras and Arellano, (2015) [1] showed improvements in a swimming start after the application of conditioning exercises imitating the leg emplacement of the swimmer on the block start. Those routines included free-weight and eccentric-resistance lunges exercises in order of activating the hip and knee extensor muscles of the front leg, causing the main impulse in track starts (6). Therefore, both routines for lower body were also adhered to our protocols. This study aimed to assess the effects of two types of activation protocols based on PAP, on sprint swimming performance. Both protocols consisted of exercises for lower and upper limbs by which attempted to replicate the impulse from the block-start and the arms strokes pulling movements. One of the protocols was based on maximal load repetitions performed on an adapted Smith machine, and the other consisted of maximal repetitions of exercises performed on an adapted eccentric flywheel. Our hypothesis is that protocols based on PAP could generate better results for 50-m swimming performance by taking advantage of performance improvements in the first 15 m.

METHODS:

Experimental approach to the problem

A repeated-measures counterbalanced design was utilized to determine differences between standard swimming warm up and two PAP-based warm up protocols on 50-m performance. First (Day 1), all of the participants performed a standard warm-up, which consisted of a 400-m swimming warm-up followed by dynamic lower and upper limb stretching and it was considered the control (testing protocol denoted SWU). Similarly to the study of Hancock, Sparks and Kullman, (2014) [5], the swimmers of the present study were allowed to rest for six min between the warm-up and the swim race. Two days later (Day 2), the swimmers were randomly assigned into two groups: the swimmers in the first group completed the SWU followed by PAP inducement through one set of three “lunge” and three “arm stroke” repetitions, both at 85% of the one-repetition maximum (Testing protocol denoted RMWU). And the swimmers in the second group completed the SWU followed by PAP inducement through one set of four repetitions of exercises of both the lower and upper limbs on an adapted eccentric flywheel at the maximal voluntary contraction (Testing protocol denoted EWU). After six minutes of rest, swimmers were tested on a 50-m race. Finally, two days later (Day 3), the group order was reversed to avoid the “fatigue/learning” effect and tests were repeated.

Subjects

Seventeen competitive male swimmers provided written informed consent and volunteered to participate in this study. Swimmers under age of 18 were asked to provide parental consent. The main physical and competitive background characteristics of the subjects (n = 17) were the following (the means ± SDs values are shown): age, 18.42 ± 1.39; body mass, 73.65 ± 8.99 kg; and height, 1.81 ± 0.02 m. All of the recruited swimmers were federated swimmers with at least 5 years of participation in regional-and national-level competitions and who underwent a complex training protocol involving at least five training sessions per week, which allows the development of power and speed while decreasing the volume of aerobic training [21].

Prior to the study, the participants visited the laboratory to become familiar with the testing methods and to determine the load required to perform a 1RM according the guidelines of the American College of Sports Medicine [22]. The arm stroke 1RM was 38.82 ± 5.29 kg, and the lunge 1RM was 93.35 ± 12.51 kg. None of the swimmers were taking drugs, medication, or dietary supplements known to influence physical performance. The tests were scheduled to occur before their daily training regimen, and the subjects were instructed to avoid any physical exertion prior to testing. All of the procedures were performed in accordance to the Declaration of Helsinki with respect to human research, and the study was approved by the ethics committee of the university.

PROCEDURES

The experimental setting was a 25-m indoor pool (with water and air temperatures of 28.1 and 29.0ºC, respectively). Every swimmer performed individually three warm-up protocols in three separate days (1 protocol per day). Upon arrival, reference points were marked (in black) on the joints of the hip, knee, ankle and hand. Subsequently, the swimmers were accurately informed about the testing protocol, which involved a rest period of six min prior to a 50-m race performed at maximum intensity. Each test was only performed once to simulate the conditions of competition, i.e., "an attempt" (FINA rules). Throughout the session, a collaborator controlled the rest time for each subject. An auditory stimulus, similar to the one used in competition was used as starting signal. In each trial, the subject was asked to mount the block, and once in position, the subject was given the verbal command “take your mark” shortly before the starting signal was sounded.

First, all of the swimmers performed the standard warm-up (SWU) protocol, which consisted of varied swimming paces and two starts from the wall. After swimming, the participants began their dynamic stretching protocol, which consisted of varied exercises of the musculature most closely related to jump and arm stroke performance. Each exercise was performed ten times, and the entire series was repeated twice (one series per min.). Throughout the stretching set, a collaborator ensured that the stretching protocol was performed properly and at the right pace over 4 min, and after 6 min of rest, the swimmers performed a 50-m race.

In two different sessions, the swimmers were counterbalanced and randomly assigned into two groups, according to the 50-m time achieved in the first trial. The first group performed the eccentric flywheel warm-up (EWU), which consisted of warm-up and stretching exercises as in the SWU protocol supplemented with the PAP stimulus through five-maximum repetitions on the nHANCE^{TM} Squat Ultimate device (YoYo™ Technology AB, Stockholm, Sweden). The second group performed the heavy load warm-up (RMWU), which consisted of warm-up and stretching exercises as in the SWU protocol supplemented with the PAP stimulus through arm stroke and lunge exercises on an adapted “Smith-Machine” (Technogym, Spain). In the third trial, the order was reversed: the second group performed the EWU protocol, and the first group performed the RMWU protocol. During the protocols, a collaborator controlled the initial position and the specific loads provided to the swimmer’s device harnesses.

STRENGTH TESTS AND CONDITIONING EXERCISES

Arm Stroke and Lunge Strength Test

A “Smith Machine” (Technogym, Spain) was adapted to perform both conditioning exercises. The incremental strength test consisted on completing two repetitions with each load, with 2 min rest between loads [22]. The participants were asked to perform the complete movement at maximal velocity, return to the starting position in a controlled manner, maintain the position for 0.5 s and perform a second repetition. A linear encoder T-Force (T-Force System, Ergotech, Murcia, Spain) was used for measuring propulsive velocity, force and power during every repetition. The maximum load repetition was selected from every set.

Arm strokes were replicated according to Dominguez-Castells, (2013) [16]. A pulley system was adapted to the bar to allow development of pulling actions away from the system (Figure 8.1). All of the targeted loads were adapted and previously confirmed with an electronic dynamometer (WeiHeng®, Guangzhou WeiHeng Electronics Co., Ltd.). The swimmers started the exercise sitting in prone position on an inclined bench (45º from vertical) and then extended their arms horizontally to the front, with each hand holding one handle. The machine exerted some tension such that the arms were relaxed. The swimmers were instructed to perform a shoulder extension similar to the movements in the front/crawl or butterfly underwater phase. One repetition finished when the arms reached the trunk line, i.e., 135º shoulder extension.

The lunge exercise was replicated as described by Cuenca-Fernandez, Lopez-Contreras, (2015) [20]. The swimmers first placed their rear knee on a lifted surface at a height of 5 cm from the ground such that the leg and thigh formed a 90º angle; similarly, the entire surface of the foot of the front leg was placed on the ground such that the leg and thigh also formed a 90º angle. After the swimmers attained this initial position, they started extending the limbs. For this exercise, the swimmers were asked to place their lower limbs in the same position as that used to perform swimming starts to control which leg was placed in front or behind.

Figure 8.1. PAP Induction for Upper Limbs through the Arm Stroke conditioning exercise on an adapted "Smith Machine".

Eccentric flywheel protocols

Eccentric flywheel protocols were applied using a nHANCE^{TM} Squat Ultimate device (YoYo™ Technology AB, Stockholm, Sweden). The arm strokes were replicated according to Naczk, Naczk, (2016) [17]. The participants laid in prone position on the stationary bench in front of the inertial device, and their legs were held by an assistant. The participants maintained their arms along their body and flexed approximately 90º at the elbow joint. The swimmers held the handles connected to the ropes, which were fully extended and tensed (hands in pronation; Figure 8.2). During the 10-s maximal trial, the participants attempted to imitate the arm stroke in the upsweep phase. The swimmers were instructed to perform the exercise as rapidly as possible. During testing, the elbow extensor and back muscles worked concentrically during the elbow extension movement (the flywheel was accelerated during this phase) and eccentrically during elbow flexion (the swimmers attempted to extend their elbow throughout the exercise, and elbow joint flexion was forced by the mass of inertia of the flywheel). The range of motion of the elbow joint was approximately 90º.

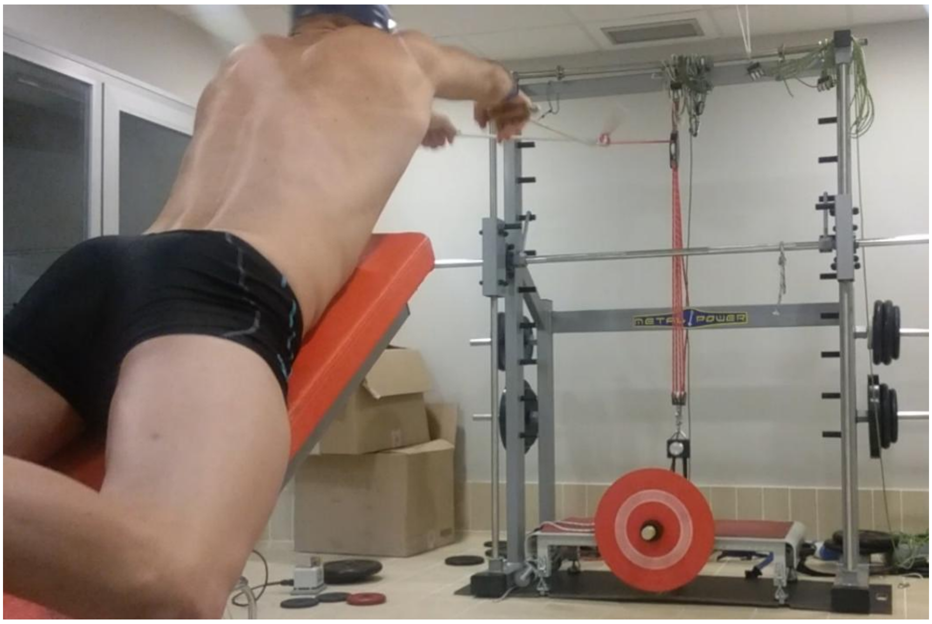


Figure 8.2. PAP Induction for Upper Limbs through the Arm Stroke conditioning exercise on an adapted nHANCE ULTIMATE®.

Lower limb extension was replicated according to Cuenca-Fernandez, Lopez-Contreras, (2015) [20] . The initial position was the same as that performed by swimmers on the block, with the same front/behind placement of the lower limbs. Once the belt was attached, the swimmers performed five maximum-intensity repetitions. The number of repetitions was selected as five because the first repetition serves to charge the flywheel.

KINEMATIC MEASUREMENTS

Data collection for the 50-m Race

Each trial was recorded with five digital video cameras. One of these was mounted on a tripod focused to the block (Casio, HS Camera 60 Hz), operated at a sampling rate of 60 Hz and used to record the kinematic variables associated to the swimming start (Block time, dive distance & velocity, angles of take-off & entry). The block camera was focused on the starting system to spot the light emitted by the starting signal. The starting system (Signal Frame, Sportsmetrics) simultaneously emitted an audible signal and a strobe flash to allow synchronization of the starting signal with the video image. The four other digital video cameras (Sony Video Camera, 50 Hz) were fixed on the poolside and registered the underwater phase from 5 to 50 m. The four sequences were overlapped in space and time by a video switcher (Digital Video Switcher SE-900). These cameras recorded the swimming *time* and *velocity* variables from 5 to 50 m, including the SR and SL. The shutter speed was adjusted using a modality (Sport Mode) that maximized the shutter speed within the limits of the cameras being used (1/4,000 seconds), consequently minimizing any distortion in the movement of the swimmers. All video files registered were analysed by two different researchers using Kinovea® software (version 0.7.10), which allowed an accurate analysis of the reference points drawn on swimmers.

Variables measured

Block time (BT). The time from flashlight-up to the moment at which the swimmer separates from the block (s).

Dive distance (DD). The distance from the swimming pool wall under the starting block to the place where the swimmer’s fingers first contact the water (cm).

Dive velocity (DV). The distance from the place where the feet last contact the starting block to the place where the swimmer’s fingers first contact the water divided by the time elapsed during this action (m/s)

Angle of take-off (AT). The angle between the horizontal line and the line that connects the hip with the referential point on the foot at the moment of last contact between the foot and the starting block (º).

Angle of entry (AE). The angle between the horizontal line and the line that connects the hip with the referential point on the hand at the moment of first contact between the fingers and the water (º).

Underwater undulatory swimming after swim start (UUSss): The distance from the swimming pool wall under the starting block to the place of emersion above the water (m).

Underwater undulatory swimming after turn (UUS_{TU}): The distance from the swimming pool wall where the turn is performed to the place of emersion above the water (m).

Time to 5-50 m (T5M-T50M). The time from flashlight-out to the time at which the swimmer's head touches the baseline at 5-50 m (s).

Time to 25 m (T25M). The time from flashlight-out to the time at which the swimmer's feet touch the wall in which the turn is performed (s).

Split time to every 5 m. The time elapsed at every distance of 5 m along the race (5-50 m) (s).

Velocity over 5-50 m (V5-V50M). The distance of 5 m divided by the time elapsed during this action (m/s).

Isolated swimming phase (ISP)*:* Total swimming time extracting start performance time and turn. (From 10 to 25-m and 30 to 50-m) (s).

Stroke rate (SR): These values were collected at the 15-, 20-, 35- and 45-m marks and determined using a video camera with a frequency measuring function for each three arm strokes. The time elapsed during this action was divided by the number of arm strokes (to obtain the rate in Hertz) and multiplied by 60 (to obtain the cycles per minute).

Stroke length (SL): These values were collected at the 15-, 20-, 35- and 45-m marks and was obtained by diving the mean velocity by the mean SR (Hz) and multiplying by 60 (m per cycle).

STATISTICAL ANALYSES

Descriptive statistics data are expressed as the means ± SDs and confidence intervals (95%). After Saphiro-Wilk testing for normality distribution, analysis using repeated-measures one-way ANOVA was applied concerning the three protocols to determine differences on the kinematic variables within and between subjects. To detect differences between the protocols, significance was accepted at the *alpha* < 0.05 level, and paired comparisons were used in conjunction with Holm's Bonferroni method for controlling type 1 errors. All the test were carried out by using SPSS Version 21.0 (IBM, Chicago, IL, USA).

The test-retest reliability (intraclass correlation [ICC]) within and between observers was analyzed for all of the variables. Six trials (three were digitized by the researcher, and the other three were digitized by an investigator with experience in digitization management with Kinovea® software) were quantified using intra-class correlation coefficients (ICC) to assess the reliability of the digitizing process (intra, inter-observer). These correlations were calculated separately for the repeated measures of the values for all of the variables for six randomly selected subjects. The intra-observer ICC ranged from 0.96 (95% confidence interval [CI] 0.94-0.97) to 0.99 (95% CI 0.98-0.99), and the inter-observer ICC ranged from 0.97 (95% CI 0.96-0.98) to 0.99 (95% CI 0.99-0.99). These results showed high correlation and reliability.

RESULTS

The means, standard deviations and confidence intervals of all the variables for the three protocols studied are shown in Tables (8.1 and 8.2) and Figure 8.3.

Swimming Start:

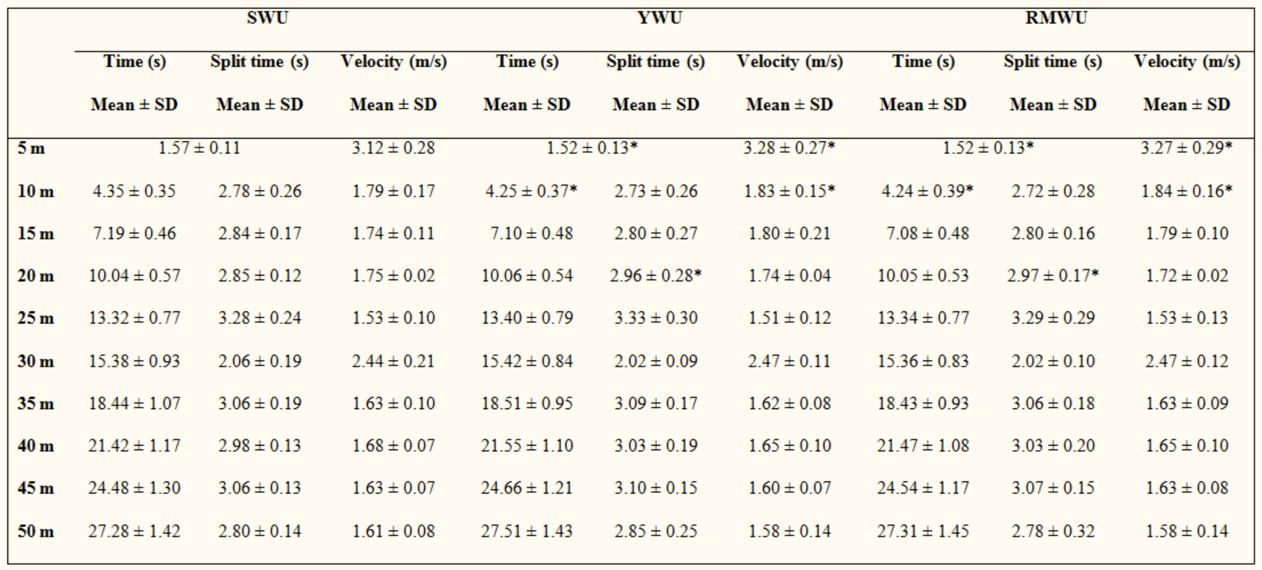
The data obtained for the block time, dive distance and diving time did not express differences (Table 8.1). For the diving velocity, the analysis revealed changes only with the EWU protocol ($F_{2,32} = 3.020$, $p = 0.048$), which yielded better values (3.40 ± 0.49 m/s) compared with those obtained with the SWU (3.26 ± 0.33 m/s) and RMWU protocols (3.31 ± 0.47 m/s). The analysis of the angles at take-off revealed differences between the SWU compared with the experimental protocols ($F_{2,15} = 4.028$, $p = 0.040$). Specifically, higher angles at take-off were found with the EWU (31.17 ± 6.40º) and RMWU protocols (32.17 ± 7.11º) than with the SWU (27.76 ± 6.14º). The analysis of the angles at entry did not reveal differences (Table 8.1). The total distance during underwater undulatory swimming was similar between the three protocols studied, both after the swimming start and after the turn (Table 8.1).

	SWU		EWU		RMWU	
	Mean ± SD	**CI (95%)**	**Mean ± SD**	**CI (95%)**	**Mean ± SD**	**CI (95%)**
BT (s)	0.658 ± 0.09	0.609 – 0.707	0.657 ± 0.079	0.616 – 0.698	0.653 ± 0.08	0.608 – 0.699
DT (s)	0.931 ± 0.09	0.881 – 0.981	0.935 ± 0.10	0.880 – 0.991	0.944 ± 0.13	0.878 – 1.012
DD (m)	3.11 ± 0.26	2.98 – 3.25	3.20 ± 0.32	3.04 – 3.37	3.14 ± 0.29	2.99 – 3.30
DV (m/s)	3.26 ± 0.33	2.97 – 3.33	3.40 ± 0.49*	3.02 – 3.39	3.31 ± 0.47	2.99 – 3.34
AT (degrees)	27.76 ± 6.14§	24.60 – 30.92	31.17 ± 6.40	27.88 – 34.47	32.17 ± 7.11	28.51 – 35.83
AE (degrees)	39.11 ± 4.37	37.16 – 41.66	40.41 ± 3.75	38.47 – 42.34	40.35 ± 4.28	38.14 – 42.55
UUSss (m)	10.09 ± 1.72	9.20 – 10.97	9.96 ± 1.71	9.07 – 10.84	10.00 ± 1.75	9.09 – 10.90
UUS_{TU} (m)	5.97 ± 1.17	5.36 – 6.57	5.58 ± 2.06	4.52 – 6.64	5.50 ± 2.05	4.44 – 6.55
ISP (s)	20.86 ± 0.95	20.37 – 21.36	21.25 ± 1.12§	20.66 – 21.83	20.97 ± 1.22	20.34 – 21.60

Table 8.1. Means, SDs and confident intervals for the variables associated with swimming start performance; underwater undulatory swimming (after the swim start and after turn); and isolated swimming phase, after the three warm-up protocols studied (n = 17).
* Differences ($p < 0.05$) in performance compared with the SWU

Swimming Time and Swimming Velocity:

The analyses revealed differences in time and velocity at 5 and 10 m (T5: $F_{2,32} = 5.133$; $p = 0.012$; V5: $F_{2,32} = 5.242$; $p = 0.011$; T10: $F_{2,32} = 3.932$; $p = 0.030$; V10: $F_{2,32} = 3.406$; $p = 0.050$). A shorter time and a higher velocity were obtained with both experimental protocols compared with the SWU protocol (Table 8.1). No differences in time and velocity were found at any point between 15 to 50 m between the three protocols applied (Table 8.2). Analysis of split times only revealed differences in 20 m (Split_20: $F_{2,15} = 5.765$, $p = 0.014$). Isolated swimming time was slower in EWU compared with the rest of the protocols ($F_{2,15} = 3.727$, $p = 0.049$) (SWU: 20.86 ± 0.95 s; EWU: 21.25 ± 1.12 s; RMWU: 20.97 ± 1.22 s).



	SWU			YWU			RMWU		
	Time (s)	Split time (s)	Velocity (m/s)	Time (s)	Split time (s)	Velocity (m/s)	Time (s)	Split time (s)	Velocity (m/s)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
5 m	1.57 ± 0.11		3.12 ± 0.28	1.52 ± 0.13*		3.28 ± 0.27*	1.52 ± 0.13*		3.27 ± 0.29*
10 m	4.35 ± 0.35	2.78 ± 0.26	1.79 ± 0.17	4.25 ± 0.37*	2.73 ± 0.26	1.83 ± 0.15*	4.24 ± 0.39*	2.72 ± 0.28	1.84 ± 0.16*
15 m	7.19 ± 0.46	2.84 ± 0.17	1.74 ± 0.11	7.10 ± 0.48	2.80 ± 0.27	1.80 ± 0.21	7.08 ± 0.48	2.80 ± 0.16	1.79 ± 0.10
20 m	10.04 ± 0.57	2.85 ± 0.12	1.75 ± 0.02	10.06 ± 0.54	2.96 ± 0.28*	1.74 ± 0.04	10.05 ± 0.53	2.97 ± 0.17*	1.72 ± 0.02
25 m	13.32 ± 0.77	3.28 ± 0.24	1.53 ± 0.10	13.40 ± 0.79	3.33 ± 0.30	1.51 ± 0.12	13.34 ± 0.77	3.29 ± 0.29	1.53 ± 0.13
30 m	15.38 ± 0.93	2.06 ± 0.19	2.44 ± 0.21	15.42 ± 0.84	2.02 ± 0.09	2.47 ± 0.11	15.36 ± 0.83	2.02 ± 0.10	2.47 ± 0.12
35 m	18.44 ± 1.07	3.06 ± 0.19	1.63 ± 0.10	18.51 ± 0.95	3.09 ± 0.17	1.62 ± 0.08	18.43 ± 0.93	3.06 ± 0.18	1.63 ± 0.09
40 m	21.42 ± 1.17	2.98 ± 0.13	1.68 ± 0.07	21.55 ± 1.10	3.03 ± 0.19	1.65 ± 0.10	21.47 ± 1.08	3.03 ± 0.20	1.65 ± 0.10
45 m	24.48 ± 1.30	3.06 ± 0.13	1.63 ± 0.07	24.66 ± 1.21	3.10 ± 0.15	1.60 ± 0.07	24.54 ± 1.17	3.07 ± 0.15	1.63 ± 0.08
50 m	27.28 ± 1.42	2.80 ± 0.14	1.61 ± 0.08	27.51 ± 1.43	2.85 ± 0.25	1.58 ± 0.14	27.31 ± 1.45	2.78 ± 0.32	1.58 ± 0.14

Table 8.2. Means and SDs for the swimming times (from 5 to 50 m), split times (each 5 m) and swimming velocities (each 5 m), collected from a 50-m race after the three warm- up protocols studied (n = 17).

* Differences ($p < 0.05$) in performance compared with the SWU

† Differences ($p < 0.05$) in performance compared with other experiemental protocol.

§ Differences ($p < 0.05$) in performance in the comparison of all of the studied protocols.

Swimming Patterns:

The swimmers showed similar values for stroke rate at the 15-, 20- and 45-m marks (Figure 8.3). At the 35-m mark, some differences were detected for the stroke rate between the protocols ($F_{2,15} = 3.651$, $p = 0.049$). The value obtained with the SWU protocol was higher from that obtained with the EWU and RWMU protocol (SWU: 58.24 ± 6.99 cyc/min; EWU: 55.51 ± 5.66 cyc/min; RMWU: 56.28 ± 6.05 cyc/min)

The statistical analysis only revealed differences in stroke length at 15-m mark ($F_{2,15}$ = 4.215, p = 0.042). The values obtained with the experimental protocols were higher than with the SWU protocol (Figure 8.3). No other differences between the protocols were identified in stroke length at 20-, 35- and 45-m marks.

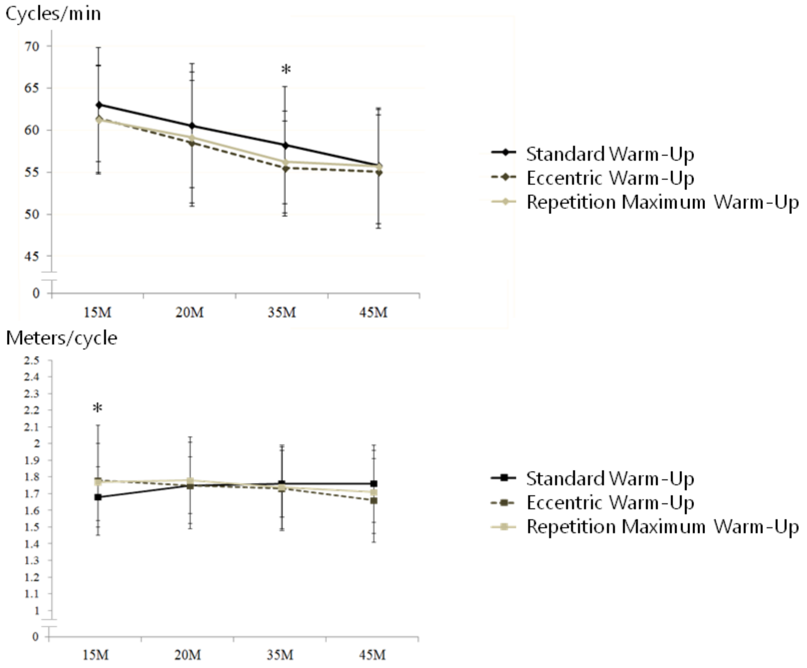


Figure 8.3. Stroke rate (SR) and stroke length (SL) on four different point marks (15, 20, 35 and 45 m) for the three protocols studied (n=17).

DISCUSSION

The purpose of this study was to assess the effects of two types of activation protocols based on PAP, on sprint swimming performance (50-m). One of these methods was based on maximal load repetitions of exercises for the lower and upper limbs performed in an adapted Smith Machine, and the other consisted of maximal repetitions of exercises for the lower and upper limbs performed on an adapted eccentric flywheel. The results obtained suggested that protocols based on PAP could generate improvements in the first 15 m. However, due to either fatigue or a modification in the swimming patterns, the final performance obtained with the experimental protocols was not better than that obtained with the SWU.

A deterioration of performance in *time* and *velocity* was obtained after the experimental protocols along the 50 m race. Nevertheless, better results were recorded in mentioned protocols at the beginning of it (Table 8.2). Analyses of the diving velocity and take-off angle yielded superior values, i.e., faster and higher values, with the experimental protocols, specifically after EWU (Table 8.1), unequivocal evidences that some gains on performance were registered on the block as a consequence of the PAP warm-ups. In addition, this improved performance was transferred to the swimming time and velocity at the beginning of the race (5 and 10-m marks). At these points, the swimmers have just entered the water and have not executed actions other than gliding or underwater swimming [3]. Therefore, these aspects would confirm that improvements possibly would arise from gains in impulse at swim start obtained specifically on lower limbs with the experimental warm-up protocols [1].Supporting the influence of PAP on swimming start [1].

The best total swimming time (50 m), was not influenced by any of the PAP protocols. The differences at this point were slight (~ 0.13 s), very similar to what experienced by the eight finalists on 50-m freestyle at the Olympics in Rio 2016 (~ 0.14 s) (www.fina.org). However, statistical significance was not achieved. At this point, dealing with such incongruence is inevitably. If a hundredth of a second may decide between winning or losing a race, the differences in performance obtained after PAP would lead swimmers to a more disadvantageous scenario. According to Stewart and Hopkins, (2000)[16], a strategy intended to change an athlete's performance must suppose an equivalent to at least ~ 0.5 % of the coefficient of variation to be considered effective. The changes on the coefficient of variation in performance collected in this study showed lower values (~ 0.4%). Thus, the null hypothesis may not be rejected. Nonetheles, in order to increase our statistical power, swimming phase was isolated (extracting start performance time and turn) and results showed that the strategy used concretely in the EWU deteriorated the swimming phase considerably. Specifically, the intra-individual variability raised to ~ 0.25 s compared with SWU and it meant a worsening of ~ 1.05 % on the coefficient of variation. Therefore, it is possible to conclude that the warm-up protocol made on the eccentric flywheel may affect the swimming phase adversely.

This fact was explained by analyzing the swimming patterns. In spite of the results indicated greater values for stroke length after the PAP protocols in comparison with the SWU at 15 m (EWU ~ 7%; RMWU ~ 6%), those values showed a downward trend from this point onwards, specially accused in EWU, (Figure 8.3). Furthermore, stroke rating was lower after PAP warm-ups, and specially accused at 35 m in comparison with SWU (Figure 8.3).

Therefore, the downward trend obtained in the swimming velocity after PAP warm-ups between 35 to 50 m may be linked to these factors. A better performance was indeed obtained at 15-m with the experimental protocols (Table 8.2). However, it is difficult to conclude whether PAP exerted a positive influence for the final result. The progressive deterioration on the results in stroke length values along with the progressive decrease experienced in the swimming velocity seemed to be the result of fatigue caused by the experimental warm-ups on the upper limbs.

In light of above, even though PAP was seen on lower limbs immediately, fatigue on upper limbs were observed soon after the start of the race. In the musculoskeletal system, muscles generate force and transmit that force via tendons to bone. A greater force generated by muscle is associated with the transmission of more stress through the tendon. Increases in the power requirement of our muscles (e.g., with speed) require a stiffer tendon to produce optimal efficiency and to produce the required power with a given muscle volume [8]. Logically, each body offers limits conditioned by its own structure. In swimming, the anthropometric nature is important because larger limbs allow larger joint levers and it might exerts a marked influence on propulsion [11]. However, it is important to consider that larger joint levers are related to higher muscle demands and it might provoke greater fatigue [8]. If the experimental protocols did induce greater fatigue on the subjects, specially on upper limbs, it is reasonable that the swimmers were unable of maintain satisfactory swimming patterns at the end of the race [13].

In conclusion, a PAP-based warm-up protocol might influence sprint swimming performance (50-m). The results suggest that performance in the first meters of a trial could be improved by a warm-up that includes swimming and heavy conditioning exercises for both the upper and lower limbs. Nevertheless, other factors, such as fatigue, can exert an influence in modifying swimming patterns, which could yield results that are contrary to those of the desired task. Considering the results of the present study, possibly the volume of the conditioning activity applied on lower limbs was appropriated, but exaggerated for upper limbs, concretely after eccentric overload. Actually, one of the limitations of our study may reside in the fact that time of rest given after upper limbs stimulation was the same even though the PAP warm-up protocols were different. Future research should identify if suitable conditioning activity, testing different loads and rest times may induce greater adaptations on upper limbs than identified on the present study. The inclusion of familiarization training in the habitual warm-up protocol also could induce favourable adaptations on the swimmers.

PRACTICAL APPLICATIONS

Nowadays, is common to see how swimmers prepare for racing by activating themselves on many different ways such as doing ballistic stretching, by increasing their breathing and heart rate, or by strongly clapping their chest or limbs. Whether or not those methods really have an influence is not part of this study. However, it cannot be rejected the fact that sprint swimmers need to create an extra activation on their system in order to race at the best of their capacities. The relevance of our study is that swimmers could find benefits from loaded stimulation protocols before a sprint race, at least on the first metres of the race. Considering the given outcomes, coaches could have the opportunity to adapt these basics to competitive constraints or individual characteristics on each case. Two aspects of interest emerged from this study; the first resides on the fact that swimmers could benefit from strength/resistance training in swimming as long as they keep the ability to transfer it into the water propulsion within appropriate swimming patterns. Meaning that stronger swimmers could benefit from a technique of swimming based on long distances per stroke; the second resides on monitoring the strength parameters of the athletes by performing a strength test biomechanically similar to the real action, as swimming coaches should make more emphasis on the control and strength development of their swimmers.

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CHAPTER IX

- STRENGTH TESTING AND CORRELATIONS IN SWIMMING

ABSTRACT

Introduction: PAP benefits are more effective when including a rest period of 6-8 minutes after a submaximal stimulus application or when it is applied to trained subjects or individuals with a high proportion of fast fiber. However, comparisons are not possible if is unknown a value of that state of training. ***Methods:*** Firstly, it was studied the relationship between maximal load on the arms collected in a dry-land repetition maximum test (Arms RM), with the performance in a swimming race 50-m. Afterwards, were applied two Postactivation-Potentiation (PAP) specific warm ups in order to analyze their effect in performance considering the Arms RM of the subjects. Trained swimmers (n=17) volunteered in this study. *Pearson* product-moment correlation coefficients were used to verify the relationship between Arms RM and kinematic variables of a 50-m swimming race. ***Results:*** Results revealed high correlation between Arms RM and performance in the swimming race, even after the application of the three warm-up protocols (Time in 50-m: SWU: R = -0.601, p = 0.011; EWU: R = -0.487, p = 0.047; RMWU: R = -0.634, p = 0.006). ***Conclusion:*** After PAP, swimmers with higher Arms RM showed a higher improvement on the kinematic variables of 50-m swimming race than those with lower values of strength.

KEY WORDS: Warm-Up, Short events, Dry-land testing, PAP, eccentric flywheel device.

RESUMEN

Introducción: los beneficios de PAP son más efectivos cuando se incluye un período de descanso de 6-8 minutos después de una aplicación de estímulo submáxima o cuando se aplica a sujetos entrenados o individuos con una alta proporción de fibra rápida. Sin embargo, las comparaciones no son posibles si se desconoce el valor de ese estado de entrenamiento. **Métodos:** En primer lugar, se estudió la relación entre la carga máxima en los brazos recogidos en una prueba máxima de repetición máxima (Brazos RM), con el rendimiento en una prueba de natación de 50-m. Posteriormente, se aplicaron dos calentamientos específicos de Potenciación post-activación (PAP) para analizar su efecto en el rendimiento considerando el RM adquirido de los sujetos. Dieciesiete nadadores entrenados se ofrecieron como voluntarios en este estudio. Se usaron los coeficientes de correlación producto-momento de Pearson para verificar la relación entre las RM de los brazos y las variables cinemáticas de una carrera de natación de 50-m. **Resultados:** Los resultados revelaron una alta correlación entre la RM de brazos y el rendimiento en la carrera de natación, incluso después de la aplicación de los tres protocolos de calentamiento (Tiempo en 50 m: SWU: R = -0.601, p = 0.011; EWU: R = - 0,487, p = 0,047; RMWU: R = -0,634, p = 0,006). **Conclusión:** después del PAP, los nadadores con mayor RM de brazos mostraron una mayor mejoría en las variables cinemáticas de una prueba de natación de 50 m que aquellos con valores de fuerza más bajos.

INTRODUCTION

The development of strength is crucial in swimming training [6]. Among many different swim-specific strength training protocols, a key criticism is that the applied loads and training intensities are not always adequately matched to the age and ability of swimmers [4]. This may in effect reduce training effectiveness. Furthermore, trainers typically neglect training that focuses on overall physical development, instead, they focus on sport-specific exercises and drills. This is unfortunate, as general exercise and low-intensity aerobic training are important in the global development of young athletes and may influence future performance and competitive success. Particularly in the case of young athletes, training that focuses on improving power output should be involve individually-determined intensity and load. In swimming, the most immediate and measurable form of biofeedback is the generated muscular force [7]. Hence, the ability to measure the force produced by swimmers could allow for the real-time control of training and therefore optimizing training potential.

Effective swimming training should include several dry land exercises, the most common of which are weight lifting, core stability exercises and other drills that involve pulling movements to train kinetic chains. Similar to in-water swimming training, training load (and the execution velocity of the exercises) also should be tailored to the individual swimmer. One common problem is that while information on training intensity and execution velocity is provided *a priori*, young and inexperienced swimmers often have problems with maintaining the prescribed intensity level. This can lead to cases of over-training, where the training load can exceed exercise capacity causing injury and performance stagnation or even regression [1]. On the opposite end of the spectrum, not reaching the target load due to inadequate exercise intensity of inappropriate exercise velocity could lead to undertraining and performance attenuation. Hence, real-time feedback of exercise execution is particularly warranted to avoid these detriments.

The first aim of this study was to test the effectiveness of a novel specific strength test designed to evaluate the arm stroke strength and correlate the results obtained in dry-land conditions with the data obtained on the water. The second aim was to evaluate such relationship after the application of two specific PAP protocols. If more strong individuals are considered to perform a swim sprint race in better conditions and PAP is more effective in trained athletes, it supposed that best trained swimmers would be able to react better after PAP application and perform a swimming race with better guarantees than weaker athletes. However, comparisons are not possible if is unknown a value of that state of training. In this study we offer the repetition maximum test (RM), as a way of obtaining such categorization

METHODS

Subjects:

Seventeen competitive male swimmers provided written informed consent and volunteered to participate in this study. Swimmers under age of 18 were asked to provide parental consent. The main physical and competitive background characteristics of the subjects (n = 17) were the following (the means ± SDs values are shown): age, 18.42 ± 1.39; body mass, 73.65 ± 8.99 kg; and height, 1.81 ± 0.02 m. All of the recruited swimmers were federated swimmers with at least 5 years of participation in regional-and national-level competitions and who underwent a complex training protocol involving at least five training sessions per week, which allows the development of power and speed while decreasing the volume of aerobic training [21].

Strength test:

Testing was performed in the Swimming Laboratory belonging to the Faculty of Sport Sciences of the University of Granada (Spain). Participants reported to the research laboratory after having refrained from alcohol, caffeine, and strenuous exercise for the previous 48 h. The task under study was the butterfly stroke (propulsion phase only) performed in the horizontal position on a modified Smith Machine. The Smith Machine was connected to the T-Force System (Ergotech, Murcia, Spain), an isoinertial dynamometer connected to a computer that provides real-time information on performance during resistance training. The system automatically distinguishes the repetitions and phases of an exercise, providing data on various biomechanical variables.

The study began with the participants performing a dry land warm-up. An incremental force test was then administered to determine the range of load in which maximal power could be produced by each participant. Next, the range of velocity which corresponded to this load was determined. In this phase, the participant had to perform thirty maximal repetitions with increasing load (5, 10, 15, 20, 25, 30 kg). The test was aborted if the participant was unable to complete a repetition. If the participant completed the test with the final 30 kg load (with increasing power), the load was increased by successive 5 kg increments. This allowed the proper pull load within a range of mean propulsive velocity to be obtained for each participant and thus prescribe similar exercise intensity for all participants.

Testing Procedures:

First, all of the swimmers performed the standard warm-up (SWU) protocol, which consisted of varied swimming paces and two starts from the wall. After swimming, the participants began their dynamic stretching protocol, which consisted of varied exercises of the musculature most closely related to jump and arm stroke performance. Each exercise was performed ten times, and the entire series was repeated twice (one series per min.). Throughout the stretching set, a collaborator ensured that the stretching protocol was performed properly and at the right pace over 4 min, and after 6 min of rest, the swimmers performed a 50-m race.

In two different sessions, the swimmers were counterbalanced and randomly assigned into two groups, according to the 50-m time achieved in the first trial. The first group performed the eccentric flywheel warm-up (EWU), which consisted of warm-up and stretching exercises as in the SWU protocol supplemented with the PAP stimulus through five-maximum repetitions on the nHANCE^{TM} Squat Ultimate device (YoYo™ Technology AB, Stockholm, Sweden). The second group performed the heavy load warm-up (RMWU), which consisted of warm-up and stretching exercises as in the SWU protocol supplemented with the PAP stimulus through arm stroke and lunge exercises on an adapted “Smith-Machine” (Technogym, Spain). In the third trial, the order was reversed: the second group performed the EWU protocol, and the first group performed the RMWU protocol. During the protocols, a collaborator controlled the initial position and the specific loads provided to the swimmer’s device harnesses.

Variables Correlated:

Time to 50 m (T50M). The time from flashlight-out to the time at which the swimmer's head touches the baseline at 50 m (s).

Velocity at 15, 20, 35 and 45 m (V15-45M). The distance divided by the time elapsed during this action (m/s).

Isolated swimming phase (ISP)*:* Total swimming time extracting start performance time and turn. (From 10 to 25-m and 30 to 50-m) (s).

Stroke rate (SR): These values were collected at the 15-, 20-, 35- and 45-m marks and determined using a video camera with a frequency measuring function for each three arm strokes. The time elapsed during this action was divided by the number of arm strokes (to obtain the rate in Hertz) and multiplied by 60 (to obtain the cycles per minute).

Stroke length (SL): These values were collected at the 15-, 20-, 35- and 45-m marks and was obtained by diving the mean velocity by the mean SR (Hz) and multiplying by 60 (m per cycle).

Statistical Analysis

Standard statistical methods were used for the calculation of means, standard deviations (SD) and *Pearson* product-moment correlation coefficients to verify the relationship between load lifted on strength tests and kinematic variables of a 50-meter swim race. Analyses were performed using SPSS software version 21.0 (IBM, Chicago, IL, USA).

RESULTS

	SWU	EWU	RMWU
	Mean ± SD	**Mean ± SD**	**Mean ± SD**
T_50m (s)	27.28 ± 1.42	27.51 ± 1.43	27.31 ± 1.45
ISP (s)	20.86 ± 0.95	21.25 ± 1.12	20.97 ± 1.22
SR_15m (cyc/min)	59.92 ± 1.46	59.15 ± 1.30	59.07 ± 1.28
SR_20m (cyc/min)	57.44 ± 1.51	56.03 ± 1.36	56.34 ± 1.45
SR_35m (cyc/min)	55.43 ± 1.35	54.01 ± 1.09	54.29 ± 1.17
SR_45m (cyc/min)	53.00 ± 1.34	52.89 ± 1.33	53.62 ± 1.30
SL_15m (m/cyc)	1.69 ± 0.03	1.74 ± 0.05	1.75 ± 0.04
SL_20m (m/cyc)	1.76 ± 0.03	1.77 ± 0.04	1.79 ± 0.04
SL_35m (m/cyc)	1.72 ± 0.03	1.75 ± 0.04	1.74 ± 0.04
SL_45m (m/cyc)	1.79 ± 0.04	1.76 ± 0.04	1.75 ± 0.04

Table 9.1. Mean and standard deviations of kinematic measurements after the three protocols (n = 17)

	SWU		EWU		RMWU	
	Load (kg)	**P**	**Load (kg)**	**P**	**Load (kg)**	**P**
T50m (s)	-.601	.011	-.487	.047	-.634	.006
ISP (s)	-.638	.006	-.478	.052	-.532	.028
Vel_15m (m/s)	.383	.129	.124	.635	.484	.049
Vel_20m (m/s)	.516	.034	.473	.055	.386	.126
Vel_35m (m/s)	-575	.016	.593	.012	.619	.008
Vel_45m (m/s)	.598	.011	.441	.076	.519	.033
SR_15m (cyc/min)	.196	.451	-.234	.367	-.190	.465
SR_20m (cyc/min)	.304	.236	-.350	.168	-.304	.235
SR_35m (cyc/min)	.205	.430	-.483	.050	-.415	.098
SR_45m (cyc/min)	.014	.957	-.494	.044	-.449	.070
SL_15m (m/cyc)	.077	.769	.213	.412	.395	.117
SL_20m (m/cyc)	-.080	.761	.348	.171	.370	.143
SL_35m (m/cyc)	.126	.629	.588	.013	.577	.015
SL_45m (m/cyc)	.230	.374	.547	.023	.553	.021

Table 9.2 Pearson's correlation coefficient between Maximal Load Arms and kinematic swimming variables (n=17).

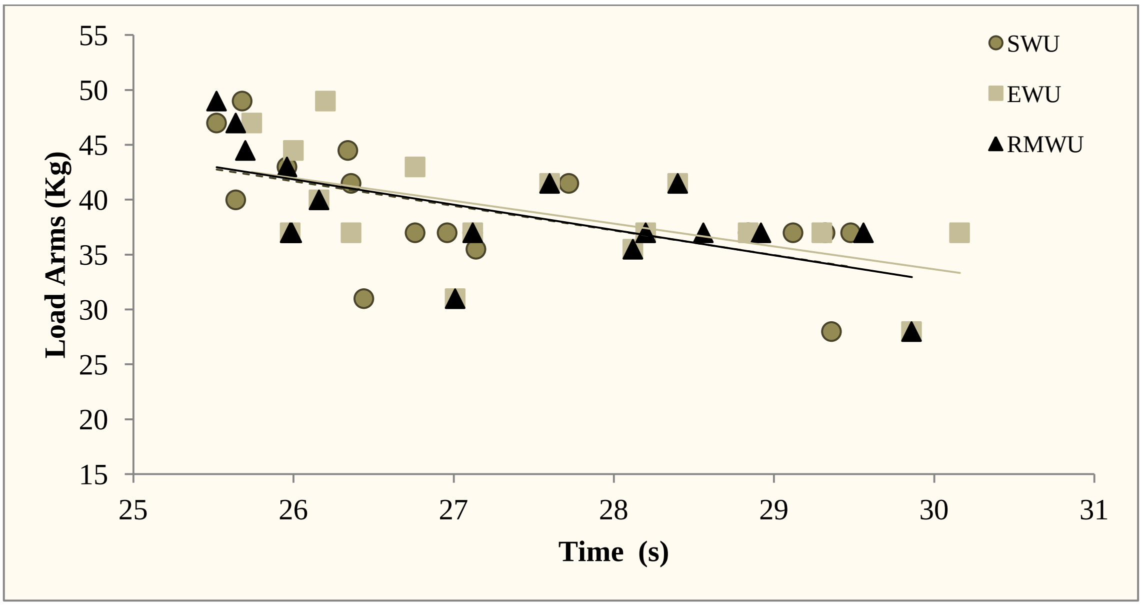

Figure 9.1. Regression analysis between Maximal Load Arms and Time to 50-meters.

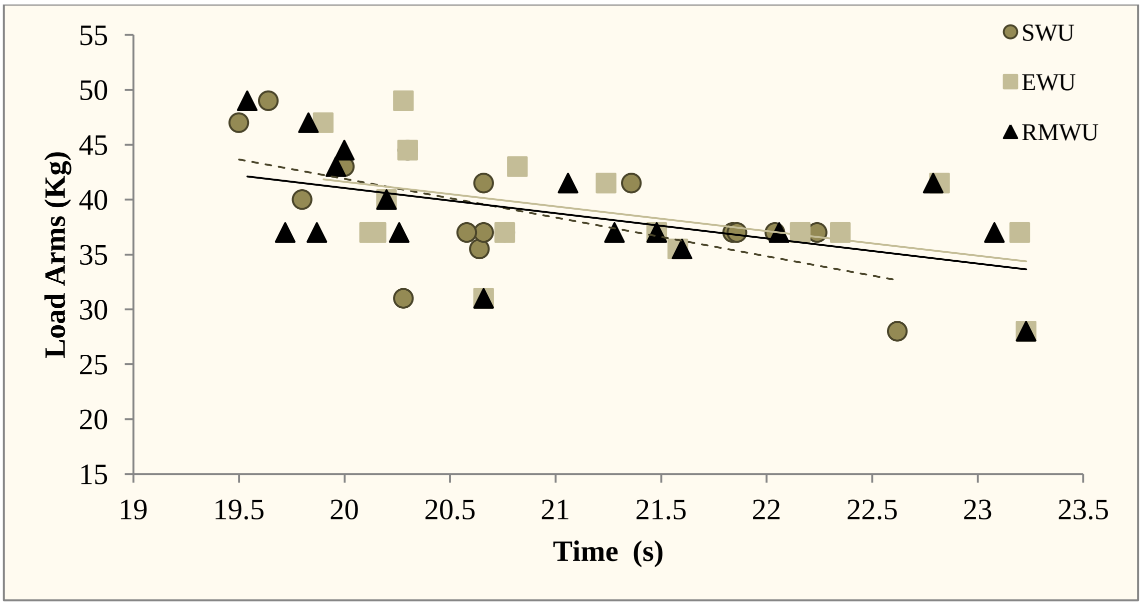

Figure 9.2. Regression analysis between Maximal Load Arms and Isolated Swimming Phase.

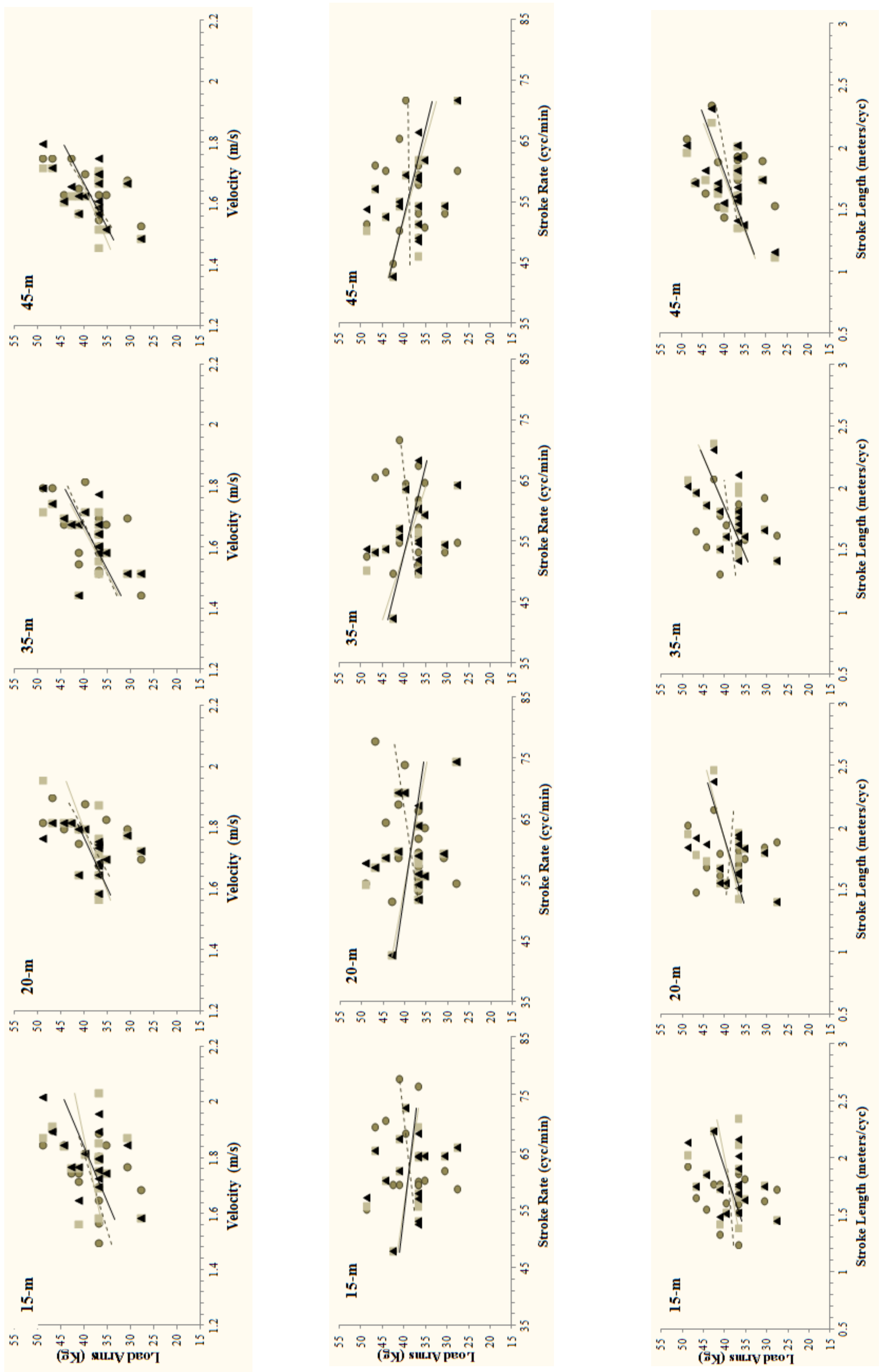

Figure 9.3. Regression analysis between Maximal Load Arms and Velocity, Stroke Rate and Stroke Length collected at 15, 20, 35 and 45-m marks.

DISCUSSION

The first aim of this study was to test the effectiveness of a novel specific strength test designed to evaluate the arm stroke strength and correlate the results obtained in dry-land conditions with the data obtained on the water before and after applying PAP protocols. Our results demonstrated that the stronger swimmers (high load pull), were able of completing the task (50-meter swimming race) in less time and higher velocity. Given the results obtained, evaluating the RM arm stroke's test through specific devices simulating the movement of the swimmer on the water, might be a reliable factor for correlating the strength of the subjects with performance in swimming.

Relationships among resistance exercise and swim performance were previously studied by Dominguez et al., (2013) [2], replicating the front crawl underwater phase through adapted devices. The subjects laid in prone position on a 45º inclined bench, extended their arms horizontally to the front, and pulled two handles connected to ropes, which were fully extended and tensed into the device, replicating the biomechanical gestures of swimming. The results, showed that maximum power on the arm stroke exercise was relatively similar to maximum swim power ($r = 0.91$), and both of these powers were related to swim velocity ($r = 0.85$, $r = 0.72$). The results obtained on the present study are in agreement with those obtained by Dominguez et al., (2013).

Swimming time was negatively correlated with the load pulled with the arms on the three protocols (Table 9.2), which means that stronger swimmers identified on dry-land conditions might complete the task in better conditions. Furthermore, same correlations were found among the experimental protocols, which mean that only the strongest ones were able of maintaining performance along the race. Isolated swimming phase also correlated with Arms RM, however, no significance was obtained after EWU, showing that conditioning exercise intensity possibly was exaggerated, inhibiting performance even on the strongest swimmers and consequently, the possibility of swimming faster. These results are in agreement with Morouço et al., (2011) [5], who affirmed that 50-m performances are more strongly associated with the absolute force values than with the relative ones (normalized to body mass).

Although the force production capability might be expected to relate muscle and body mass, in swimming this relationship might be affected by the specific ability of a swimmer to apply force in the water [5]. Considering velocity of swimming, some interesting results were found depending on the protocol studied. At SWU, it correlated with the Arms RM at 20, 35 and 45-m marks. Indicating that the strongest or highly conditioned swimmers maintained a high velocity for longer; even on the last part of the race. On the other hand, velocity collected at RMWU correlated with Arms RM at 15, 35 and 45-m marks. The correlation found at 15-m possibly was due to an appropriated stimulus for the upper limbs. However, benefits at this point might be the result of an improved swimming start performance, as was showed in previous chapters of this thesis. Regarding to EWU, only velocity at 35-m marks correlated with Arms RM. Furthermore, a general deterioration of performance was identified on this protocol, which means that eccentric protocol produced higher fatigue on the swimmers than the others.

Analyzing swimming patterns, no relation was found at any point between Arm RM and stroke rate. Neither in the SWU nor in RMWU, suggesting that strongest swimmers identified through strength testing may benefit of a type of swimming based in less strokes. In fact, only after EWU protocol, a trend indicated that the strongest swimmers swam the race with less strokes, specially by negative correlation between Arm RM and swimming velocity found at the end (35 and 45-m). This fact was confirmed by analyzing the relations found for Stroke Length and Arm RM, they were significant also at 35 and 45-m. Both after the experimental protocols and at the end of the race. Which gives logical results supporting the aforementioned statement, based on the assumption that a given stroke rate, the strongest swimmers might benefit of applying more strength on propulsion in order to achieve longer distances per stroke. A greater force generated by muscle is associated with the transmission of more stress through the tendon. Increases in power in strength requirements of our muscles (e.g. with speed) require a stiffer tendon to produce optimal efficiency and to produce the required power with a given muscle volume. Consequently, higher muscle requirements also produce higher fatigue. Therefore, the deterioration found specially after EWU, might be the result of a misbalance between fatigue and potentiation. And is reasonable that swimmers were unable of maintaining satisfactory swimming patterns at the end of the race.

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CHAPTER X

- CONCLUSSIONS/CONCLUSIONES
- APPLICABILITY AND FUTURE RESEARCH AREAS / APLICACIONES PRÁCTICAS Y FUTURAS ÁREAS DE INVESTIGACIÓN
- ACKNOWLEDGMENTS / AGRADECIMIENTOS

CONCLUSSIONS

1. The optimum performance occurs when the fatigue has dissipated and the enhancement still exists.

2. There was a significant negative correlation between how well our participants performed at Pre- test relative to the other test days and PAP effects. This finding has implications for the testing of individual athletes, where an exemplar Pre performance would decrease the likelihood of seeing PAPE, and *vice versa*. This variability should be accounted for when assessing the effectiveness of a particular warm-up procedure. Future studies could benefit from the use of a large number of Pre tests to differentiate normal variability in performance from true PAPE effects.

3. The PAP found in the chapter II following the control protocol was a surprising result which suggests that the modest performance enhancements seen in that study were a warm-up effect, probably caused by the SJ and PPU test protocol itself. Nevertheless, in spite of results would be related with the physiological theory of Postactivation Potentiation, evoked by myosin phosphorilation, neuromuscular factors could contain the effectiveness key of such effect.

4. The hypothesis that PAP could produce a systemic effect was refused. Changes happened in limbs after specific load application, but no influences were found when load applied in such limb was assessed in the other. When load was applied on legs, them showed variations in impulse and EMG as a consequence of that load. When such a load was applied on arms, them reacted in a same way than legs. But them did not receive any influence from each other.

5. The protocols which included an specific PAP application showed better results than the standard warm up on swimming start performance. Specifically, the application of flywheel inertial device (YWU) would be the most appropriate warm up for performing a swimming start in the best condition because improves the take-off velocity and therefore may be especially relevant in short events.

6. Subjects with higher values in F_{REL} showed to react better after PAP application, especially after YWU, which confirms that PAP effects are bigger the more specific is it applied and the more trained subjects are. Most trained individuals were able of performing a swimming

start with better guarantees. To author’s knowledge no one had measured this before considering the feet on an asymmetric placement.

7. By applying a conditioning exercise based on repetitions on eccentric flywheel, improvements on a swimming start performance would come due to the improvement obtained in the vertical axes of force production. It suggests that slight increments in the vertical components of force/impulse, rather than in the horizontal vectors of it, might be crucial for obtaining improvements on a swimming start performance.

8. PAP might influence sprint swimming performance (50-m). The results suggest that performance in the first meters of a trial could be improved by a warm-up that includes swimming and heavy conditioning exercises for both the upper and lower limbs. Nevertheless, other factors, such as fatigue, can exert an influence in modifying swimming patterns, which could yield results that are contrary to those of the desired task. Possibly the volume of the conditioning activity applied on lower limbs was appropriated, but exaggerated for upper limbs, concretely after eccentric overload.

9. Evaluating the RM arm stroke’s test through specific devices simulating the movement of the swimmer on the water, might be a reliable factor for correlating the strength of the subjects with performance in swimming. The strongest swimmers assessed in dryland conditions performed the swimming race in better conditions. Furthermore, they reacted better to PAP warm-up protocols.

CONCLUSIONES

1. El rendimiento óptimo ocurre cuando la fatiga se ha disipado y la potenciación todavía existe.

2. Existió una significativa correlación negativa entre el rendimiento de los participantes en el pre-test en comparación con los otros pre-test tomados en los demás días y los efectos de PAP. Este hallazgo tiene implicaciones para las evaluaciones con atletas, donde un rendimiento ejemplar en el pre-test disminuiría la probabilidad de ver PAP en el post-test, y viceversa. Esta variabilidad debe tenerse en cuenta al evaluar la efectividad de un procedimiento particular de calentamiento. Los estudios futuros podrían beneficiarse del uso de un mayor número de pruebas en el pre-test para diferenciar la variabilidad normal en el rendimiento de los verdaderos efectos PAP.

3. El PAP encontrado en el capítulo II después del protocolo de control fue un resultado sorprendente que sugiere que las modestas mejoras de rendimiento observadas en ese estudio fueron un efecto del calentamiento, probablemente causado por el protocolo de evaluación en sí, ya que se realizaron tres saltos y tres flexiones con salto. Sin embargo, a pesar de que los resultados estarían relacionados con la teoría fisiológica de la Potenciación de post-activación, evocada por la fosforilación de miosina, los factores neuromusculares podrían contener la clave de eficacia de tal efecto.

4. La hipótesis de que el PAP podría producir un efecto sistemático fue rechazada. Los cambios ocurrieron en las extremidades después de la aplicación de la carga específica, pero no se encontraron influencias cuando la carga aplicada en dicha extremidad se evaluó en la otra. Cuando se aplicó carga sobre las piernas, estas mostraron variaciones en el impulso y EMG como consecuencia de esa carga. Cuando tal carga se aplicó sobre los brazos, reaccionaron de la misma manera que las piernas. Pero ellos no recibieron ninguna influencia el uno del otro.

5. Los protocolos que incluyeron una aplicación de PAP específico mostraron mejores resultados que el calentamiento estándar en la ejecución de una salida de natación. Específicamente, la aplicación de la máquina de entrenamiento excéntrico (YWU) sería el calentamiento más apropiado para realizar un inicio de natación en las mejores condiciones porque mejora la velocidad de despegue y, por lo tanto, puede ser especialmente relevante en eventos cortos.

6. Los sujetos con valores más altos en F_{REL} mostraron una mejor reacción después de la aplicación de PAP, especialmente después de YWU, lo que confirma que los efectos de PAP son más grandes cuanto más específico es el estímulo que se aplica y cuanto más entrenados están los sujetos en los que se aplica. La mayoría de los individuos entrenados pudieron realizar una salida de natación en mejores condiciones. Además, hasta donde nuestro conocimiento alcanza, nadie había evaluado este tipo de elementos considerando que la colocación de los pies es asimétrica.

7. Mediante la aplicación de un ejercicio de acondicionamiento basado en las repeticiones ejecutadas en la máquina de entrenamiento excéntrico, las mejoras en el rendimiento en la salida de natación vendrían debido a la mejora obtenida en los ejes verticales de producción de fuerza. Esto sugiere que pequeños incrementos en las componentes verticales de fuerza, en lugar de en los vectores horizontales de la misma, podrían ser cruciales para obtener mejoras en el rendimiento de una salida de natación.

8. El PAP puede influir en el rendimiento en una prueba de natación de velocidad (50 m). Los resultados sugieren que el rendimiento en los primeros metros de una prueba podrían mejorarse mediante un calentamiento que incluya nado variado y un protocolo de ejercicios de acondicionamiento de alta intensidad para las extremidades superiores e inferiores. Sin embargo, otros factores, como la fatiga, pueden influir en la modificación de los patrones de natación, lo que podría producir resultados contrarios a los de la tarea deseada. Posiblemente el volumen o intensidad del ejercicio de acondicionamiento aplicado a los miembros inferiores fue apropiado, pero exagerado para los miembros superiores, especialmente después de una sobrecarga excéntrica.

9. La evaluación de la fuerza de los brazos a través de un test de Repeticiones máximas adaptado a las características biomecánicas de la tracción en natación, podría ser un factor fiable para correlacionar la fuerza de los sujetos con el rendimiento en la natación. Los nadadores más fuertes evaluados mediante test en seco realizaron la prueba de natación en mejores condiciones. Además, reaccionaron mejor a los protocolos de PAP aplicados en el calentamiento.

APPLICABILITY AND FUTURE RESEARCH AREAS.

1. Improving the fatigue resistance should be an important task for coaches because may allow greater enhancement effects after PAP. However, the adaptation of methods to competitive constraints should be resolved in the future.

2. Three SJ and three PPU offered equivalent performance benefits as the three heavy resistance exercise CAs. The acute beneficial effect of these callisthenic exercises on performance has the advantage of requiring no specialized equipment; facilitating their use pool-side during competitions.

3. One relevant point of this thesis is the application of a system used in explosive gestures (eccentric flywheel) in the field of aquatic sports such a swimming start performance, which has been observed to improve the performance of swimmers, especially in short events. The effect on velocity at take-off leads us to recommend the application prior to competition in short events. However, given the unfeasibility of using it six minutes prior to getting on the block or while waiting in the call-up room, lead us to recommend it preferably as an interesting training tool for coaches, as an extension movement can be effectively performed with lower limbs. Therefore, the possible modifications induced on technique as well as the adaptations of this kind of methods to competitive constraints should be resolved in the future.

4. The F_{REL} is a reliable factor for correlating the strength of the subjects with performance developed in an specific task as swimming start performance. It provides to the coach an easy tool for measuring the state of training of their subjects because it considers the body weight of the subject when mobilizing loads.

5. Swimmers could benefit from strength/resistance training in swimming as long as they keep the ability to transfer it into the water propulsion within appropriate swimming patterns. Meaning that stronger swimmers could benefit from a technique of swimming based on long distances per stroke.

6. Monitoring the strength parameters of the athletes by performing a strength test biomechanically similar to the real action, is an interesting factor as swimming coaches should make more emphasis on the control and strength development of their swimmers.

7. The inclusion of familiarization training based on PAP in the habitual warm-up protocol also could induce favourable adaptations on the swimmers.

APLICABILIDAD DEL ESTUDIO Y FUTURAS ÁREAS DE INVESTIGACIÓN

1. Mejorar la resistencia a la fatiga debería ser una tarea importante para los entrenadores, ya que puede permitir mayores efectos de mejora después de la potenciación post-activación. Sin embargo, la adaptación de los métodos a las limitaciones que supone la competición debería resolverse en el futuro.

2. Tres saltos y tres flexiones con salto ofrecieron beneficios en el rendimiento equivalentes a los de los tres ejercicios de acondicionamiento de alta intensidad. El efecto beneficioso agudo de estos ejercicios calisténicos sobre el rendimiento tiene la ventaja de no requerir ningún equipo especializado; facilitando su uso junto a la piscina durante las competiciones.

3. Un punto relevante de esta tesis es la aplicación de un sistema utilizado en gestos explosivos (máquina de entrenamiento excéntrico) en el ámbito de los deportes acuáticos, especialmente para potenciar el rendimiento de la salida de natación en pruebas cortas. El efecto sobre la velocidad en el despegue nos lleva a recomendar su aplicación antes de las pruebas de velocidad. Sin embargo, dada la inviabilidad de usarlo seis minutos antes de subir al poyete (mientras se espera en la cámara de llamada), nos lleva a recomendarlo preferiblemente como una herramienta de entrenamiento interesante para los entrenadores, ya que el movimiento de extensión se puede realizar de manera efectiva. En cualquier caso, las posibles modificaciones inducidas en la técnica, así como las adaptaciones de este tipo de métodos a las limitaciones de la competición, deberían resolverse en el futuro.

4. El índice de Fuerza relativa (F_{REL}) es un factor útil y fiable para relacionar la fuerza de los sujetos con la ejecución de una tarea específica como es la salida de natación. Proporciona al entrenador una herramienta fácil para medir el estado de entrenamiento de sus sujetos porque considera el peso corporal del sujeto cuando moviliza cargas.

5. Los nadadores podrían beneficiarse del entrenamiento de fuerza en la natación, siempre que mantengan la capacidad de transferirlo a la propulsión en el agua dentro de unos patrones de técnicos apropiados. Lo que significa que los nadadores más fuertes podrían beneficiarse de una técnica de natación basada en una mayor longitud de brazada.

6. Monitorizar los parámetros de fuerza de los atletas realizando una prueba de fuerza biomecánicamente similar a la acción real, es un factor interesante ya que los entrenadores de natación deberían hacer más énfasis en el control y el desarrollo de la fuerza de sus nadadores.

7. La inclusión del entrenamiento de familiarización basado en PAP en el protocolo habitual de calentamiento también podría inducir adaptaciones favorables en los nadadores.

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APPENDIX

EFFECT ON SWIMMING START PERFORMANCE OF TWO TYPES OF ACTIVATION PROTOCOLS: LUNGE AND YOYO SQUAT

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ABSTRACT

Cuenca-Fernández, F, López-Contreras, G, and Arellano, R. Effect on swimming start performance of two types of activation protocols: Lunge and YoYo squat. *J Strength Cond Res* 29(3): 647–655, 2015—The purpose of this study was to compare the effects of 2 protocols of postactivation potentiation (PAP) on swimming start perfomance (SS). Fourteen trained swimmers (10 men and 4 women) volunteered for this study. An intragroup design of randomized repetitive measurements was applied. A previous SS trial, performed after a standard warm-up (SWU), served as a reference. Two methods of PAP, performed after 1 hour of rest, were randomly added to the SWU: (a) 3 lunges at 85% of 1 repetition maximum (LWU) and (b) 4 repetitions on the flywheel device YoYo squat (YWU). Swimmers were tested in an SS 8 minutes after the PAP warm-ups. Kinematic variables were collected using 3 underwater digital video cameras fixed poolside and operating at 25 Hz, and 1 high-speed camera focused on the block and operating at 300 Hz. Data obtained from the video analysis were processed using a repeated measures analysis of the variance. The mean horizontal velocity of the swimmer's flight improved after both PAP methods, with the greatest improvement after YWU ($F_{2,12} = 47.042$, $p < 0.001$; SWU = 3.63 ± 0.11; LWU = 4.15 ± 0.122; YWU = $4.89 \pm 0.12\ \text{m}\cdot\text{s}^{-1}$). After YWU, it took the subjects less time to cover a distance of 5 m ($F_{2,12} = 24.453$, $p < 0.001$) and 15 m ($F_{2,12} = 4.262$, $p < 0.04$). Subjects also achieved a higher mean angular velocity of the knee extension ($F_{2,12} = 23.286$, $p < 0.001$) and a reduction of the time on the block ($F_{2,12} = 6.595$, $p \leq 0.05$). These results demonstrate that muscle performance in the execution of an SS is enhanced after a warm-up with specific PAP protocols. YWU leads to the greatest improvement in the performance of the swimmer's start and, therefore, may be especially beneficial in short events.

KEY WORDS flywheel, warm up, PAP, dynamic stretching, OSB11 block

INTRODUCTION

Swimming start performance (SS) is an important component of the swimming race, especially in short events (8). It consists of explosive movements intended to propel a swimmer from the starting block into the water (9,42). Among male elite swimmers, swimming velocities are on the order of 1.8–2 $\text{m}\cdot\text{s}^{-1}$, whereas typical average velocities over the first 15 m of the race are approximately 3 $\text{m}\cdot\text{s}^{-1}$ (8,12).

Many studies have shown improvements in the execution of sporting performances after warming up (3,6,7,25,31). However, a method called postactivation potentiation (PAP) has recently received considerable attention (15,19,34,35,41). Postactivation potentiation improves muscle contractility, strength, and speed in sporting performances by applying maximal or submaximal loads on the muscle before the performance. The effects observed with PAP are the result of a physiologic alteration that renders actin-myosin myofibril more sensitive to Ca^{2+}, released from the sarcoplasmic reticulum, and an increase in muscle fiber recruitment, due to an intensification of the motor-neuron's excitation. This leads to an amplification of the muscle action potential, which improves the mechanical power and, consequently, the athletic performance (15,19,34,35,41).

Postactivation potentiation has been shown to be more effective in lower limbs when a rest period of 8 minutes is included after a submaximal stimulus application (24,29,39) because the optimum performance occurs when the fatigue has dissipated and the enhancement still exists (39); when it is applied to trained subjects or individuals with a high proportion of fast fibers (16,19,30,33,34,43); and when the PAP movement is biomechanically similar to the real movement (16,35). The use of the new Olympic OSB11 block (OMEGA, Zurich, Switzerland), which consists of a rear plate where swimmers can push with the rear foot, should therefore be considered when choosing an optimal

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BRIEF COMMUNICATION

Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: a pilot study

Francisco Cuenca-Fernández, Ian C. Smith, Matthew J. Jordan, Brian R. MacIntosh,
Gracia López-Contreras, Raúl Arellano, and Walter Herzog

Abstract: Fifteen trained athletes were assessed for postactivation performance enhancement (PAPE) of squat jumps (SJs) and power push-ups (PPUs) following upper body activation, lower body activation, upper and lower body activation, and rest. SJ improved similarly across all 4 conditions. PPU could not be assessed. Since the test protocol of SJ and PPU involved upper and lower body activation and caused PAPE in SJ, future work is required to determine if a nonlocalized PAPE effect exists.

Key words: squat jump, postactivation potentiation, voluntary contractions, muscle function, swimming.

Résumé : Dans cette étude, on évalue quinze athlètes entraînés pour vérifier l'amélioration de la performance (« PAPE ») aux sauts avec accroupissement (« SJ ») et aux pompes brachiales en puissance (« PPU ») à la suite de l'activation du haut du corps, du bas du corps, du haut et du bas du corps et d'un repos. On note une amélioration similaire de SJ dans les quatre conditions. Il est impossible d'évaluer PPU. Du fait que le protocole d'évaluation de SJ et PPU comporte une activation du haut et du bas du corps et qu'on enregistre une PAPE dans la condition SJ, il faut réaliser d'autres études pour vérifier si un effet PAPE non localisé se manifeste. [Traduit par la Rédaction]

Mots-clés : saut avec accroupissement, potentialisation postactivation, contractions volontaires, fonction musculaire, natation.

Introduction

The athletic community has shown considerable interest in the performance enhancements seen soon after a warm-up of brief, high-force contractions (conditioning activity; CA) (Sale 2004). The magnitude and time history of the enhancement depends on whether performance is assessed in electrically evoked or voluntary contractions. Enhancements of electrically evoked contractions are typically large (>20%) increases in twitch torque during the first minute after the CA and decline rapidly (Tillin and Bishop 2009; Vandenboom 2016). In contrast, enhancements of voluntary contractions are typically small (<5%) effects observable after a significant rest period, peaking 7–10 min after the CA (Maloney et al. 2014; Tillin and Bishop 2009; Wilson et al. 2013), a time when there is effectively no remaining enhancement of electrically evoked contractions. The differences between these effects have been obscured by imprecise use of terminology in the literature. The term postactivation potentiation (PAP) classically refers to enhancement of electrically evoked twitch force (Belanger et al. 1983; Vandervoort et al. 1983). This definition has not been strictly adhered to, with several papers purportedly studying PAP having only measured enhancement of voluntary activations. In this paper we refer to the enhancement of electrically evoked contractions as PAP, and the enhancement of voluntary movements as postactivation performance enhancements (PAPE).

There is strong evidence that PAP is a local effect caused by contraction-induced increases in myosin regulatory light chain (RLC) phosphorylation (Vandenboom 2016). PAPE, however, could be achieved via a number of effects unrelated to RLC phosphorylation, including increased muscle temperature (MacIntosh et al. 2012; McGowan et al. 2015; Sargeant 1987), increased recruitment of motor units (Tillin and Bishop 2009), and increased excitability or firing synchrony of motor neurons (Güllich and Schmidtbleicher 1996; Trimble and Harp 1998; Vandenboom 2016). The inotropic effects of exercise-induced elevations in plasma catecholamines (Cairns and Borrani 2015; Decostre et al. 2000) may also contribute to PAPE, but this has not been investigated in detail. Specifically, brief bouts of intense exercise can increase circulating epinephrine and norepinephrine levels (Botcazou et al. 2006). Exposure to these catecholamines enhances force in both fast and slow muscle fibres (Cairns and Dulhunty 1993). As circulating hormones, norepinephrine and epinephrine could systemically enhance muscle contraction. A nonlocalized PAPE effect is an intriguing notion; however, we are not aware of any study that has tested for PAPE in muscle groups that were not activated by the CA. Such an effect would be of great interest to the sporting world as it could circumvent the detrimental effects of neuromuscular fatigue (Pierce 1995). In this study we assessed squat jump (SJ) and power push-up (PPU) performance in trained swimmers before and after 4 different CAs: quiet standing (QS), back squat (BS), bench press (BP), and BS+BP. We hypothesized that there would be no PAPE following QS, and chose the conservative hypothesis that PAPE effects would be purely local responses.

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